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Drainage Correlation Research Project

INTERIM REPORT #4
May 1966

HYDROLOGIC STUDY OF LONE MAN COULEE

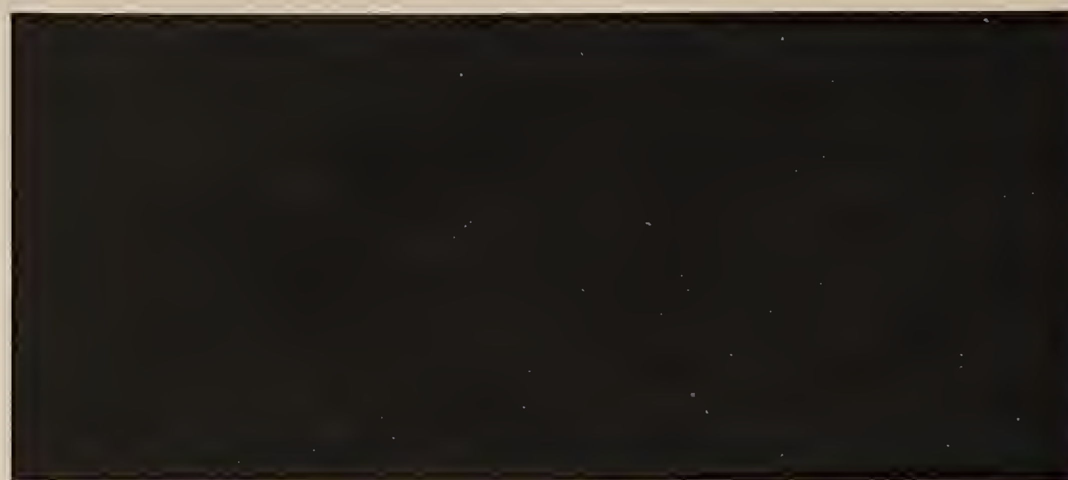
by

T. T. Williams, Lee Robinson and T. L. Hanson

ENGINEERING

Research Laboratories

MONTANA STATE UNIVERSITY, BOZEMAN



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Department of Civil Engineering and Engineering Mechanics

Montana State University, Bozeman

Prepared for

Montana State Highway Department

and

U.S. Bureau of Public Roads

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I INTRODUCTION

The purpose of this interim report is to present preliminary analyses of the hydrologic data collected to date on Lone Man Coulee. The results obtained are not considered to be at all definitive, but only show trends which can be interpreted qualitatively. The current status of the investigation and the course of action by which concrete quantitative results may be achieved are discussed.

The Drainage Correlation Research Project is an investigation of peak discharges from small Montana watersheds. The study, which is being conducted by the Department of Civil Engineering and Engineering Mechanics at Montana State University, is sponsored by the Montana State Highway Department and the Bureau of Public Roads. Four small watersheds in Montana were selected in June 1963 for intensive hydrologic instrumentation and study. Precipitation and streamflow data have been collected from the four watersheds since August, 1963. Additional instrumentation (wind speed and direction, soil and air temperature, and soil moisture) was added in July, 1964. Table I has a list of the types and numbers of instrumentation on each of the four watersheds.

The watersheds are described in detail in Interim Report #1, "Selection of Small Watersheds," May 1965. Details on the instrumentation are given in Interim Report #2, "Precipitation and Streamflow Instrumentation for Small Watersheds," and

TABLE I - INSTRUMENTED WATERSHEDS

Watershed	Nearby Town	County	Area	Recording Weighing Raingages	Non-Recording Std 8" Raingages	Continuous Water Stage Recorders	Weather Stations with Wind	Weather Stations without Wind
Bacon Creek	Harlowton	Wheatland	21.2 sq.mi.	2	3	1	1	1
Duck Creek	Brockway	McCone & Prairie	54.0	3	4	2	1	2
Hump Creek	Reedpoint	Sweetgrass	7.61	1	1	1	1	0
Lone Man Coulee	Valier	Pondera	14.1	2	2	1	1	1

Interim Report #3, "Weather Stations for Small Watersheds," July, 1965.

Since the inception of this study, several runoff events of considerable significance, including the unusual flood of June 1964, have occurred at Lone Man Coulee. A number of hydrologic techniques have been applied to the data collected thus far on the watershed, and to data collected by the U.S. Weather Bureau and U.S. Geological Survey. This report describes the current status of the investigation with regard to Lone Man Coulee.

II DESCRIPTION OF WATERSHED

Lone Man Coulee watershed is located five miles south of Valier and about two miles south of Lake Francis in Pondera County. It is a long, narrow basin (6 miles long by 2.5 miles wide) covering 14.1 square miles. The basin is an area of rolling hills with rock outcrops over some of the steeper hills. Most of the hillsides, however, have fairly light slopes.

There are two main streams which drain the basin. Miller Coulee drains about two square miles, with Lone Man Coulee draining the remainder of the watershed. There are two or three small stock ponds on part of the Miller Coulee drainage area.

The length of the main stream (Lone Man Coulee) is 7.21 miles. The length along the main stream to the point nearest the mass center of the watershed is 4.55 miles (L_{ca}). The mean slope of the main stream is 0.61 percent.

Watershed elevations range from 3775 to 4185 feet, with a mean elevation of 3910 feet.

Approximately 75 percent of the area is in strip-wheat farming. The steeper slopes are covered with native grass.

The soils in the area are predominantly loams. A generalized break-down is: 50 percent Morton loam, 25 percent Fairfield loam, and 25 percent Scobey loam.

III HYDROLOGIC DATA

Precipitation data is obtained from standard recording and non-recording rain gages which meet Weather Bureau specifications. The recording gages are dual traverse, 12-inch capacity weighing type gages. Other meteorological information is recorded

on strip charts, as described in Interim Report #3.

A continuous record of water stage has been obtained since installation of a water stage recorder at the mouth of the watershed in August 1963. A stage-discharge relationship has been developed, to convert stage readings into discharges. The stage-discharge curve is shown in Appendix A.

All data is reduced to digital form and recorded on special sheets, from which the values may be later transcribed to computer cards. Reduction of data from strip charts to the sheets has been kept up to date. Rainfall histograms, storm hydrographs, and unit hydrographs have been developed from some of the data.

Graphs showing daily precipitation at each of the four project raingages are shown in Appendix B. Appendix B also shows a tabulation of all the peak flows which have been recorded at Lone Man Coulee.

IV FREQUENCY ANALYSIS

Ordinarily, frequency studies of watersheds are based on the analysis of relatively long streamflow, or crest stage gage records. In the present study, however, records of flood peaks exist for too few years to make this type of analysis feasible. Two alternative approaches are used below: (1) comparison with other similar watersheds with long records; and (2) synthesis of frequency curves from the relationship of rainfall to runoff.

(1) Comparison with Other Watersheds

Comparison with other watersheds can be applied only to a very limited extent because few watersheds of less than 100 square miles area have long enough streamflow records to be of value. Nevertheless, two near-by watersheds, Two Medicine Creek and Badger Creek, each having 30 years of record, have been compared to Lone Man Coulee. The areas of these watersheds are 317 and 133 square miles respectively. Figure 1 shows a comparison of data from Badger Creek, Two Medicine Creek, and Lone Man Coulee on the basis of discharge rate per unit of area. This shows these watersheds to be quite comparable except for a few extreme values. The U. S. Geological Survey has developed a tentative composite flood frequency curve for eastern Montana in conjunction with the Crest Stage Gaging Program (U.S.G.S. "Interim Report on the

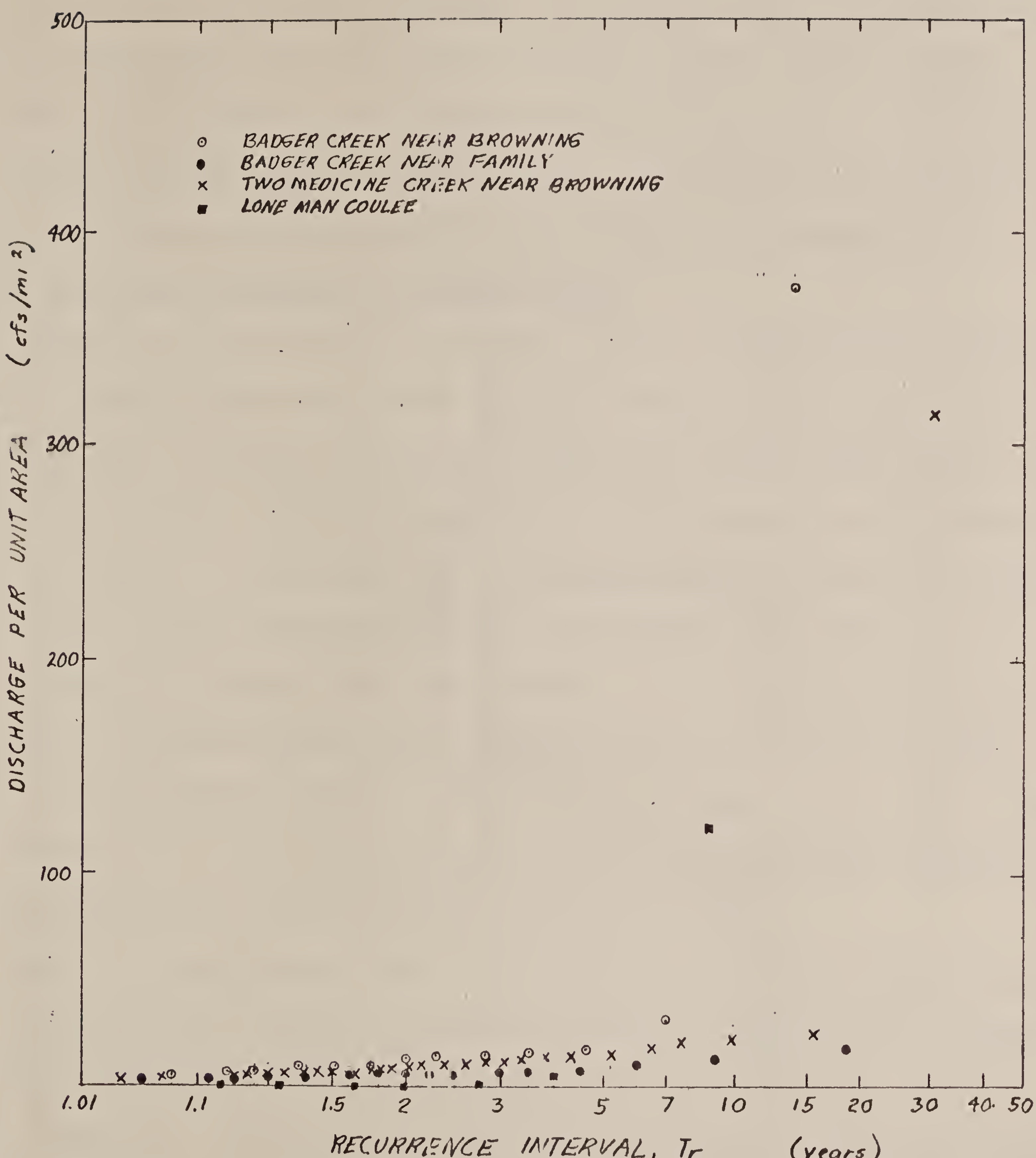


FIGURE 1: Recurrence intervals for Badger Creek, Two Medicine Creek, and Lone Man Coulee as a function of annual peak discharge per unit area.

Frequency and Magnitude of Floods in Eastern Montana, "November 1963) which uses ratio of the mean annual flood (the mean of the annual peak discharges of record) as the ordinate, and time as the abscissa. This curve was not developed for watersheds as far west as Lone Man Coulee. The data of Figure I have been replotted in terms of the ratio to the mean annual flood and compared with the U.S.G.S. composite curve in Figure 2. The frequency data for Badger Creek and Two Medicine Creek compare favorably with the U.S.G.S. curve. There are too few data points for Lone Man Coulee to determine whether any of these curves are applicable to it.

(2) Synthesis from Rainfall Frequency Curves

Synthesis of flood frequency curves from rainfall frequency data is another possible approach. Undoubtedly the relationship between rainfall and runoff is very complicated. However, for events of long, hard rainfall which produce floods of long return period, many of the complicating factors such as surface storage, non-uniform rainfall, infiltration, etc. become approximately constant or negligible. For this case a direct relationship should exist betweeen the frequency of the rain producing the flood and the flood frequency. A preliminary method to form this relationship has been developed by Mr. Robinson and is outlined briefly below.

The widely accepted procedure developed by E. J. Gumbel for applying extreme value statistics to either precipitation or runoff frequencies uses a record of largest recorded value during each year of record of either discharge rate or precipitation rate. In the case of precipitation rate the peak mean rate over a short time period, such as one hour, is usually used. The mean and standard deviation of the data are formed, from which the Gumbel frequency line is determined. For an outline of the Gumbel procedure the reader is referred to a standard hydrology test (such as Linsley, Kohler and Paulhys, "Applied Hydrology").

The old rational runoff theory indicates that for long storms with uniform precipitation rate the peak discharge rate is proportional to the precipitation rate. This suggests a proportional relationship between the Gumbel line for rainfall and the Gumbel line for runoff. To estimate the constant of proportionality, observe that

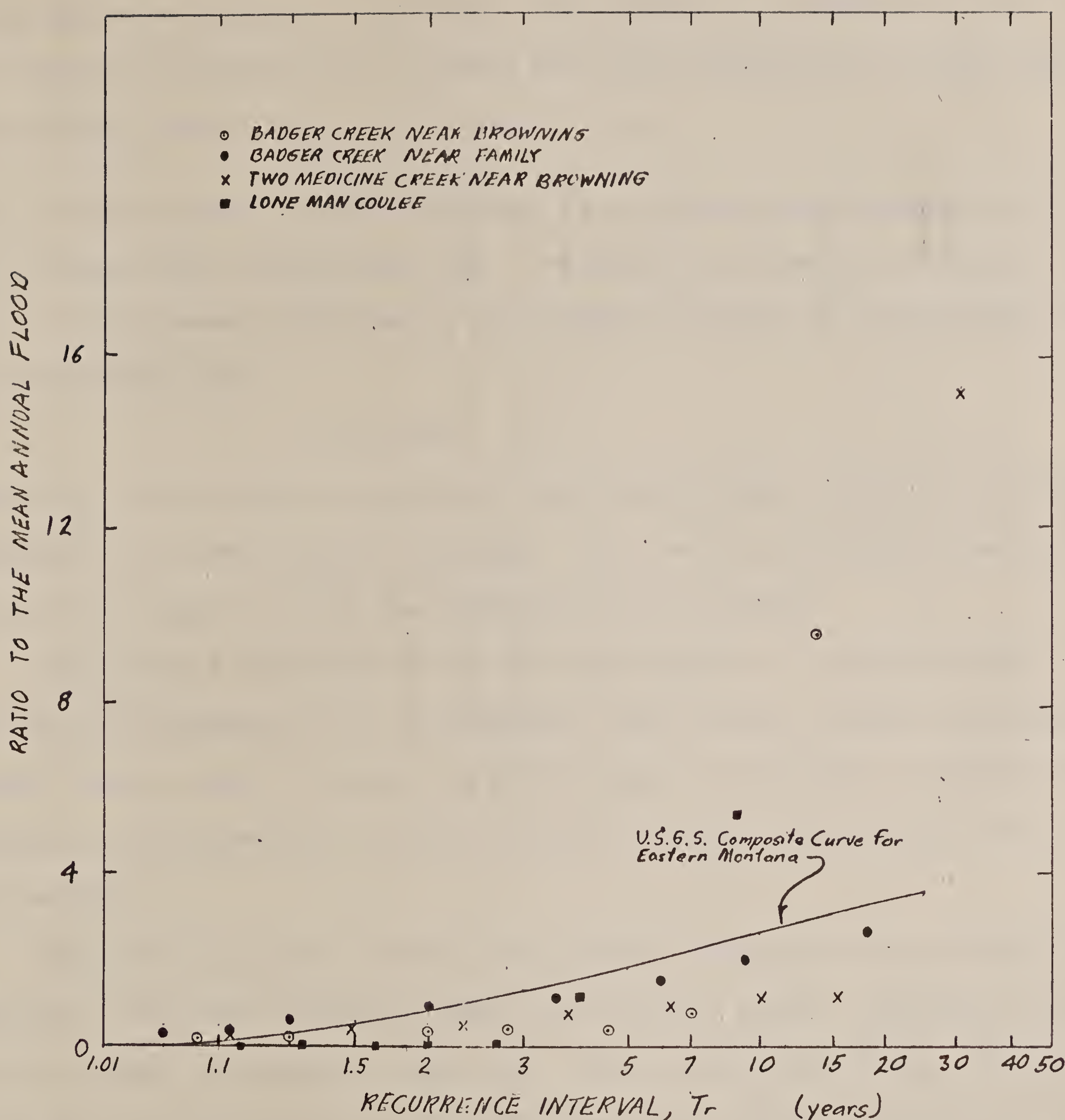


FIGURE 2: Recurrence intervals for Badger Creek, Two Medicine Creek, and Lone Man Coulee as a function of the ratio to the mean annual flood.

from statistics, the sample mean estimates the population mean with easily determinable reliability. The mean of the annual peak discharges for a short record, perhaps as short as five or ten years, will give a good estimate of the mean peak discharge for an infinitely long record. The constant of proportionality can then be estimated by comparing this estimated mean peak discharge with the mean peak precipitation rate from the rainfall record; i.e.,

$$K = \overline{YQ} \;/\; \overline{YP}$$

where K is the constant of proportionality, $\overline{Y}_Q$ is the mean peak discharge, and $\overline{Y}_Q$ is the mean peak precipitation rate. The same proportionality is assumed to hold for the standard deviations, so the standard deviation of the discharge peaks can be determined from

$$S_Q = K\ S_P$$

where, S_Q is the standard deviation of the discharge peaks, and S_P is the standard deviation of the precipitation rate peaks. From the thus determined values of $\overline{Y}_Q$ and S_Q the Gumbel line for the discharge peaks is plotted.

Some questions concerning the validity and adequacy of the above method have yet to be answered, e.g., the assumption that the use of 24-hour interval for rainfall data is valid. However, the method appears to adequately reproduce flood frequency curves generated from runoff data on watersheds where longer runoff records are available.

Throughout this type of analysis the question arises as to how reliable an estimate of the return period the Gumbel line actually gives. Confidence curves provide a useful technique for doing this. Since methods for forming confidence curves are not commonly given in hydrology tests, one method is outlined here. The theoretical basis for this method is given in Appendix C.

The equation of the abscissa of the confidence curves is given by

$$Y_{cc} = Y_{+} \pm (\text{r.s.e.})\ (S_y)\ /\sqrt{n}\,\sigma_n)$$

where Y_{+} is the ordinate of the Gumbel line (the value of the discharge or precipitation rate), r.s.e. is the reduced standard error, S_y is the standard deviation of the date, σ_n is the standard deviation of the reduced extremes, and n is the number of data values.

S_y and n are know from the statistical analysis of the data. Gumbel tabulated values of n and σ_n; these are shown in Table II.

TABLE II - Means and Standard Deviations of Reduced Extremes (after Gumbel)

n	σ_n	n	σ_n	n	σ_n
8	0.90	20	1.06	80	1.19
10	0.95	30	1.11	90	1.20
12	0.98	40	1.14	100	1.21
14	1.01	50	1.16	150	1.23
16	1.03	60	1.17	200	1.24
18	1.05	70	1.19	∞	1.28

The r.s.e. depends only on the return period (the ordinate of the confidence curves) and is tabulated in Table III.

TABLE III - Reduced Standard Error for Various Return Periods (after Gumbel)

Return Period (T_F)	Reduced Std. Error(r.s.e.)	Return Period (T_F)	Reduced Std. Error(r.s.e.)
1.01	1.85	5.00	1.98
1.10	1.35	7.00	2.03
1.50	1.08	10.00	2.68
2.00	1.18	20.00	3.38
2.80	1.34	50.00	4.32
3.00	1.37	100.00	5.03
4.00	1.76		

Thus for any values of return period, the corresponding values of Ycc can be calculated. The confidence curves are then drawn through these points. (For example, see Figure 3). These confidence curves show the interval of time within which a given flood may be expected with a probability of 2/3. Confidence curves for other probabilities may be obtained by multiplying the r.s.e. by an appropriate coefficient.

Application of the method of synthesizing runoff frequencies from rainfall frequencies to Lone Man Coulee is shown by Figures 3,4,5,6, and 7. Figure 3, Figure 4 and Figure 5 show the Gumbel lines for precipitation at several U.S. Weather Bureau stations near the watershed and the goodness of fit of the data

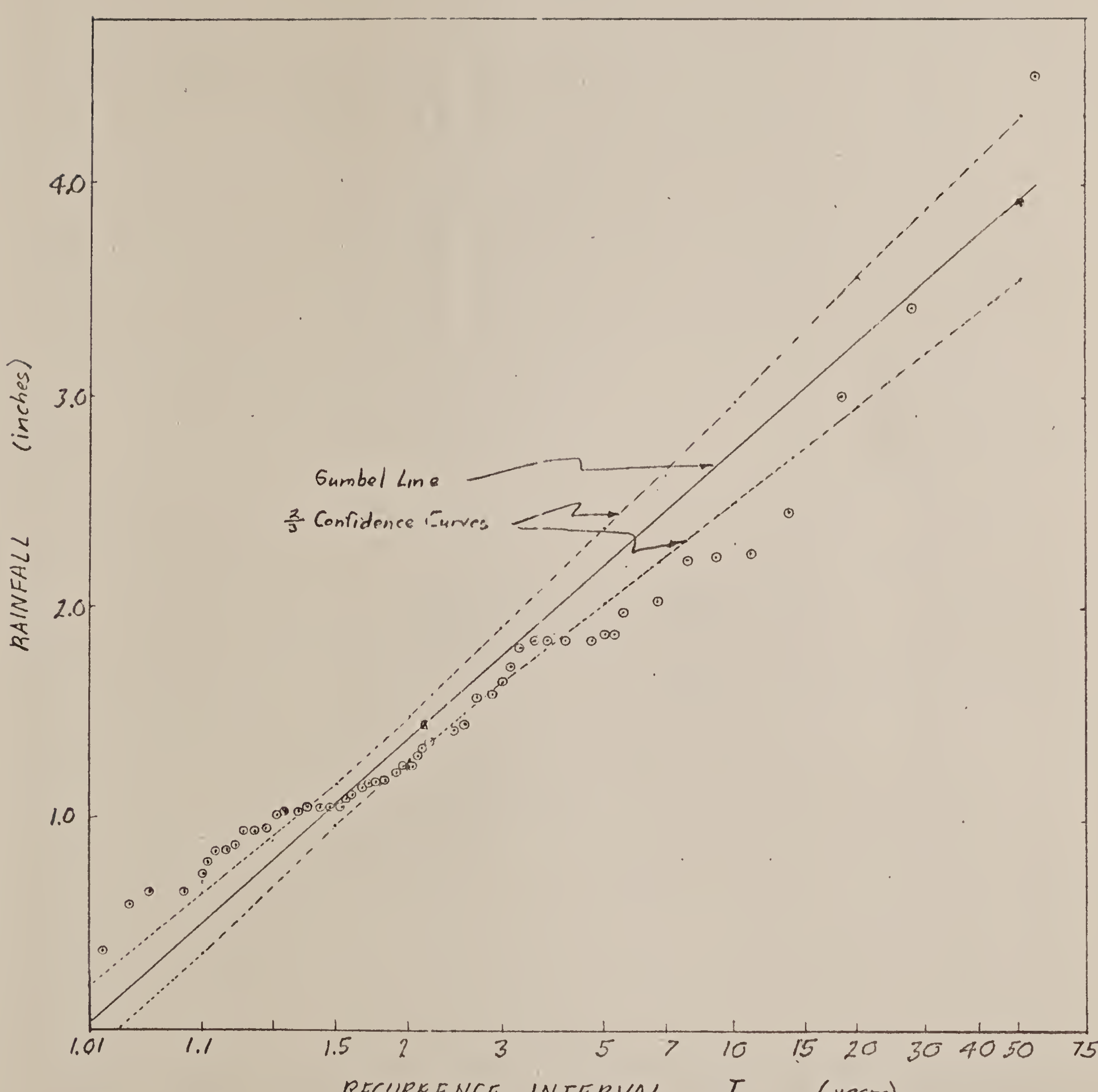


FIGURE 3: Recurrence of the annual maximum day of rainfall at Valier, Montana.

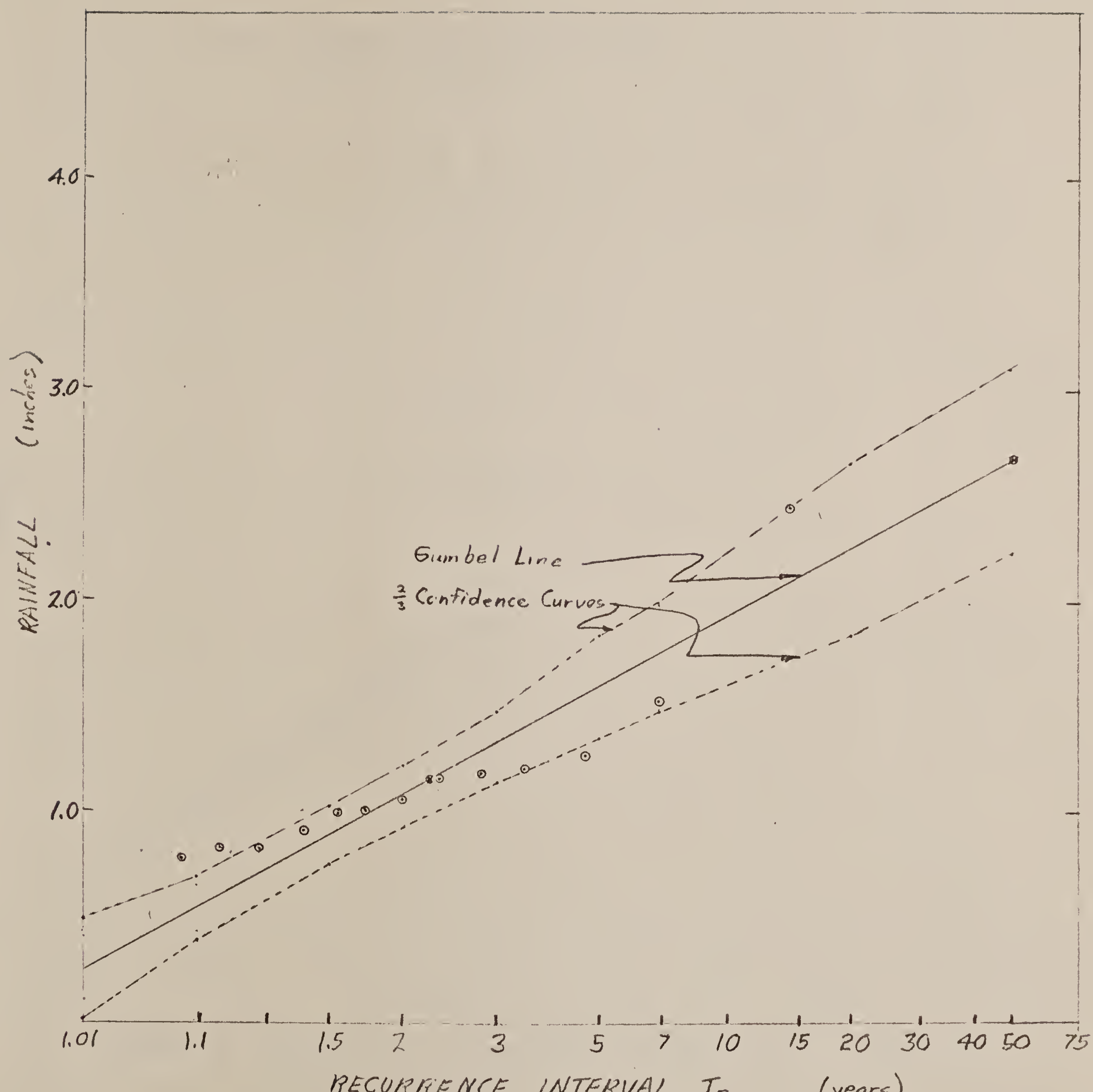


FIGURE 4: Recurrence of the annual maximum day of rainfall at Dupuyer, Montana.

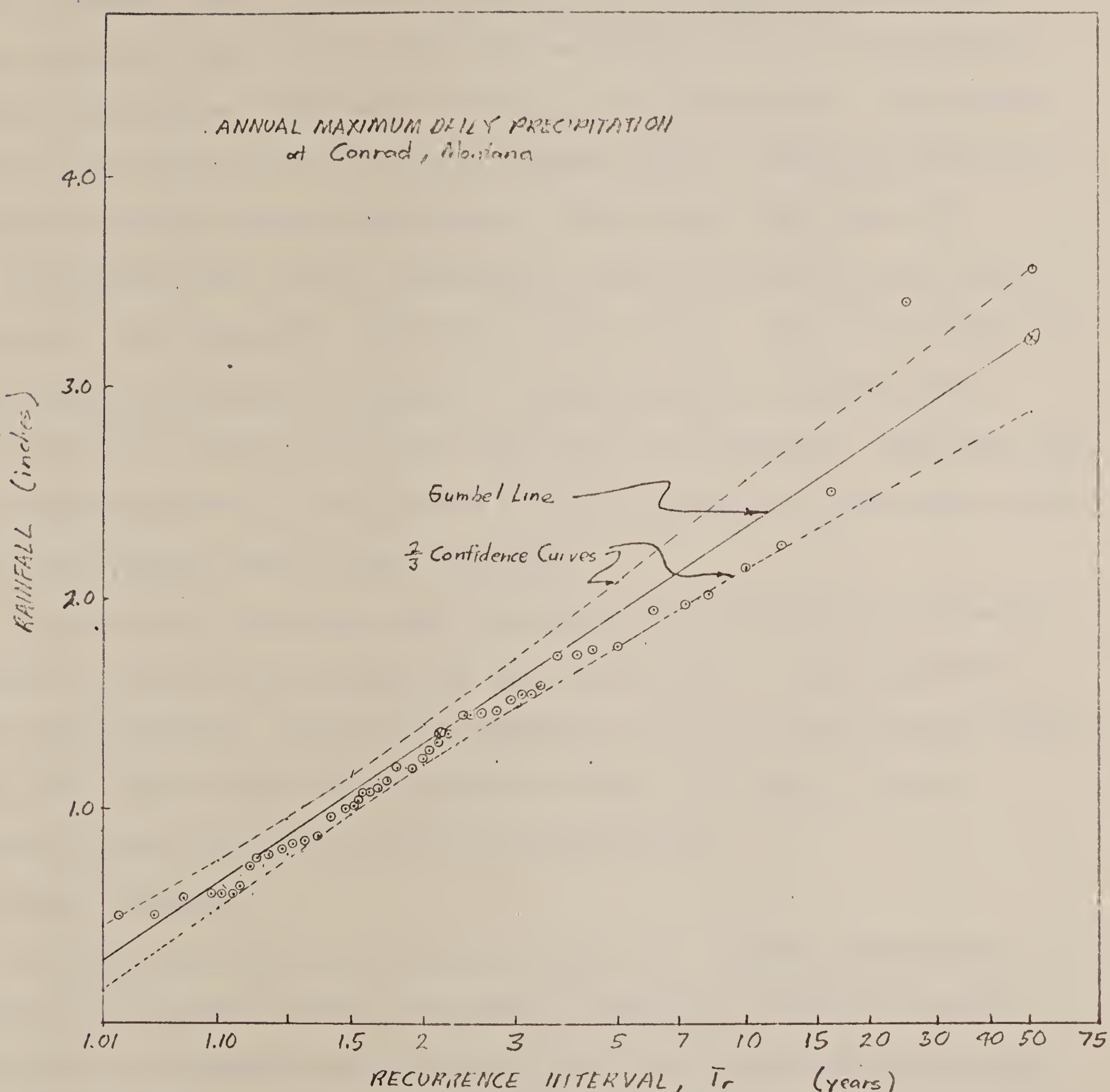


FIGURE 5: Recurrence of the annual maximum day of rainfall at Conrad, Montana.

to the 2/3 confidence curves. The Gumbel line for Conrad, which is 15 miles from the watershed, appears to have a better fit than the one for Valier, which is 5 miles from the watershed; however, the Gumbel lines for the two stations are almost identical when plotted dimensionlessly on the ordinate. Figure 6 shows the Gumbel lines for the same stations, and the weighted mean of these lines plotted with the ratio of each peak precipitation value to the mean peak value on the ordinate. This makes the lines directly comparable. The weighted mean line was formed from the individual station lines by weighting them by the distance from each station to the center of the watershed. (See Table IV)

The weighted mean line was transformed by using the equations given above to estimate S_Q (See Table IV). The values of Y_Q and S_Q were used to obtain the flood frequency line shown in Figure 7. The data points for Lone Man Coule and the U.S.G.S. composite curve are also plotted for comparison. This shows that the transformed rainfall curve predicts a smaller discharge for long return periods than do the methods based on other watersheds.

There is not a long enough record available at Lone Man Coulee to determine whether the extreme value technique is more reliable than a simple comparison with other watersheds. However both techniques point to the fact that the flood of June 1964 (the extremely high data point on Figure 1 and Figure 7) was an extremely unusual event with a very long return period.

V. MULTIPLE REGRESSION

Multiple regression is a statistical process for obtaining the best prediction of a dependent variable with several independent variables. The procedure not only determines coefficients for the independent variables, but also gives sufficient information to test the relative importance of each variable. The square of the multiple regression coefficient (R^2) also indicates the goodness of fit. An R^2 of 1.00 indicates that all experimental values are predicted exactly by the computed equation. The greater the deviation between actual and predicted values the further R^2 deviates from 1.00. Another indicator of the goodness of fit is the standard error of estimate, which

Table IV: Computations for weighting the rainfall frequency lines and transforming the weighted line to the flood frequency line.

Location	Mean annual peak day of precip.[1] Y_p (inches)	Standard Deviation of peak precip. values[1] S_p (inches)	Distance from watershed center (miles)	Weight Factor[2] w	$\overline{Y}_p \cdot w$ (inches)	$S_p \cdot w$ (inches)
Valier	1.46	.628	5	3/5	0.876	.437
Dupuyer	1.16	.438	15	3/15	0.232	.088
Conrad	1.36	.652	15	3/15	0.272	.150
Weighted Y_p[3]					1.38	
Weighted S_p[4]						0.675
Mean annual peak discharge rate (Lone Man Coulee),[5] Y_Q					320cfs	
$K = Q / \overline{Y}_p = 320/1.38$			232			
$S_Q = K\ S_p = 232\ (.675)$						157

1. Computed from annual peak days of rainfall for the years of record at each station.

2. Computed as 3/(distance from watershed center)

3. Computed as $\overline{Y}_p \cdot w$

4. Computed as $S_p \cdot w$

5. Computed from the peak annual discharges at Lone Man Coulee (See Appendix B).

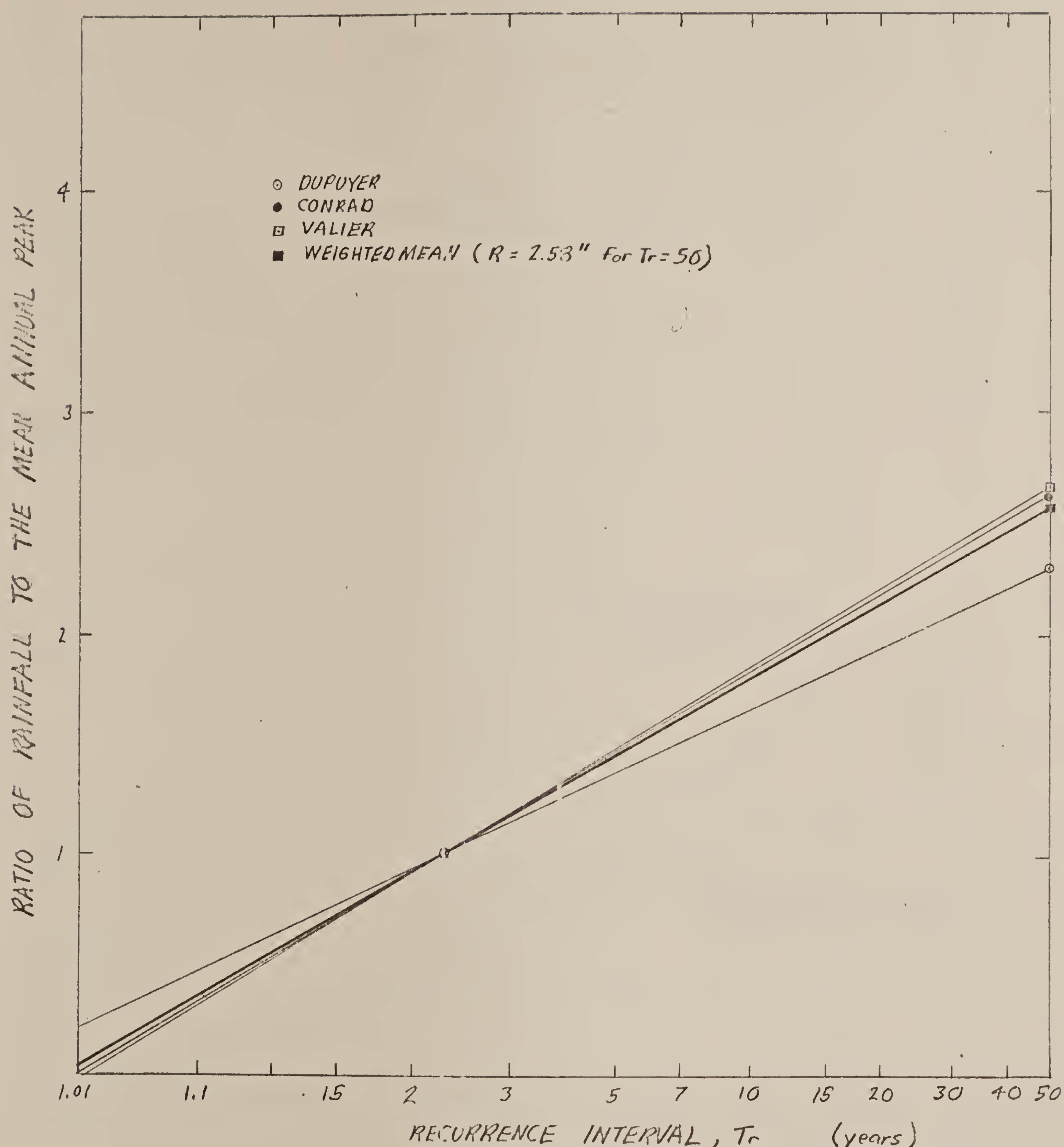


FIGURE 6: Dimensionless plot of the recurrence of the annual maximum day of rainfall.

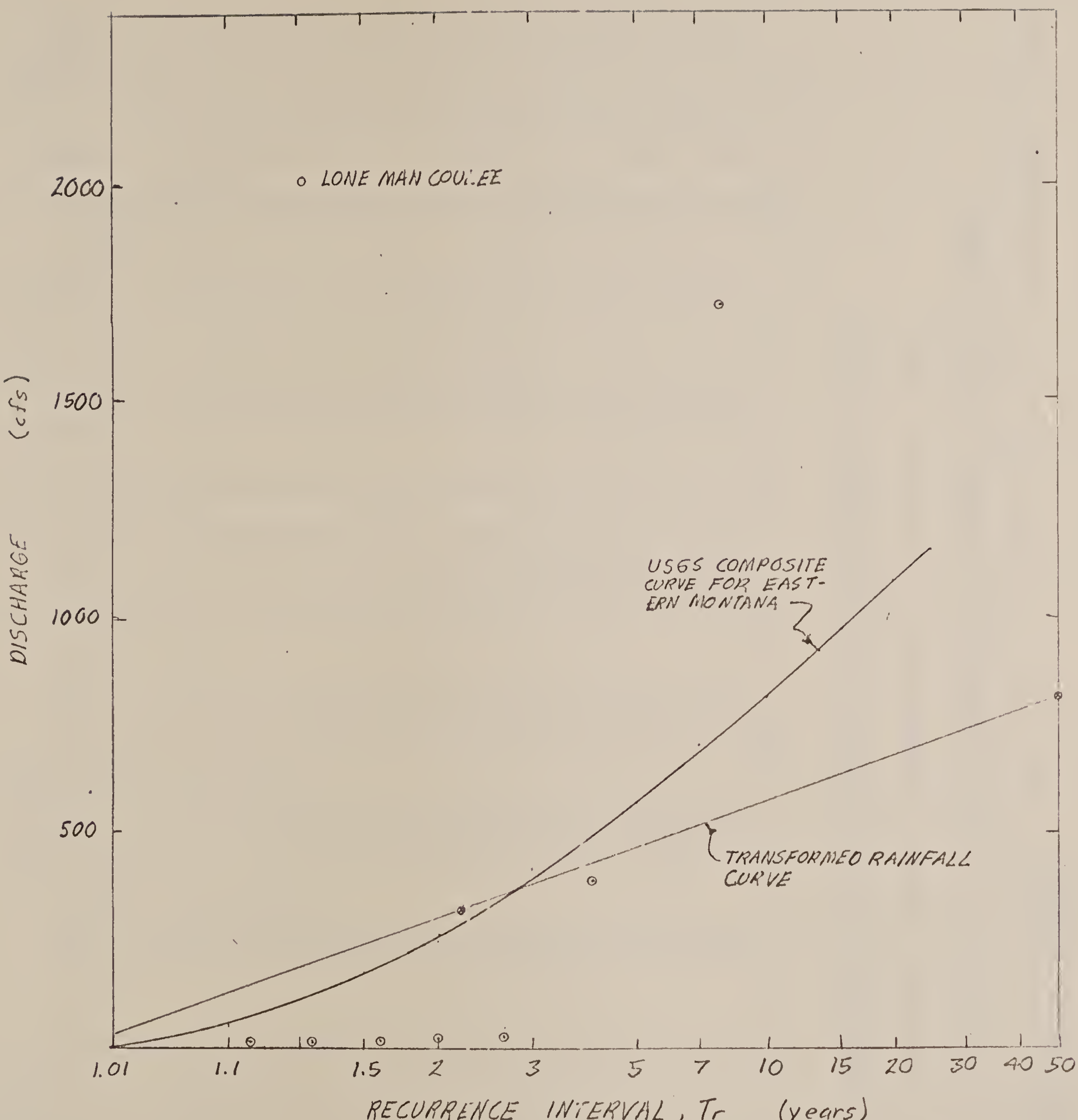


FIGURE 7: Flood frequency curve transformed from rainfall frequency curves for Lone Man Coulee compared with the U.S.G.S. composite curve.

Table V. Data for multiple regression of snowmelt events in 1965.

Date	Peak Discharge cfs	Temperature - °F			Soil Moisture Reading			Wind mph	Direction
1965	Q	[1] A_{12}	[2] A_{24}	[3] S	[4] M_3	[4] M_9	[4] M_{18}	[5] V	[5] D
2-17	390	44.9	43.4	31	3.5	4.0	3.5	33.8	2.7
2-27	29	41.7	41.2	31	4.5	4.5	3.0	27.9	3.4
3-6	7	31.5	32.2	31	5.5	5.5	3.5	10.7	4.5
3-7	8	32.6	37.0	31	7.5	6.5	3.0	7.5	5.8
3-31	34	35	39	27	3.5	3.5	3.5	7.7	4.7
4-1	68	33	29	29	4.0	3.5	3.0	8.3	5.7
4-5	63	35	30	31	10.0	5.5	4.0	7.4	5.3
4-6	240	38	36	31	11.5	5.5	4.0	11.1	5.9
4-7	60	35	35	31	15.0	5.5	3.5	4.0	4.5
4-8	17	42	37	33	20.0	6.5	3.0	5.9	5.0
4-9	11	38	35	34	25.5	13.0	3.0	8.0	6.6
4-11	18	35	32	34	25.0	31.5	4.0	15.7	1.6
4-12	18	53	41	35	25.0	34.0	6.0	6.5	3.1
4-17	32	39	32	34	23.0	37.0	9.0	22.7	2.1

[1] Average Air Temperature for both stations for 12 hrs prior to peak.

[2] Average Air Temperature for both stations for 24 hrs prior to peak.

[3] Average soil temperature for both stations for all depths for day of storm.

[4] Average relative soil moisture value at 3", 9" and 18" depths for day preceding and day of storm (4 readings/24 hrs. averaged)

[5] Average reading for precipitation period or 12 hrs prior to peak for snowmelt period wind direction 1 = N, 2 = NW, ... 8 = NE.

indicates the deviation of the data about the predicted value for any constant set of variables.

As with most statistical procedures, the larger the number of observations the greater the reliability of the prediction equation. Since there have been only 8 runoff events caused by rainfall on Lone Man Coulee for which all of the climatological data are available, no attempt was made to obtain a multiple regression equation from the rainfall-runoff data. There were 14 runoff events caused by snowmelt. Although this is still a small number of events for obtaining a good prediction of peak flow, a multiple regression analysis was made.

A list of the variables with definitions of each is given in Table V. These variables were values which were measured directly at the weather stations. The measurable watershed characteristics were not included as variables since these would be constants when studying only one watershed. Any snowmelt events with a peak flow equal to or less than 5 cfs were left out. As more data becomes available this limit might be increased to eliminate the small, frequent runoffs and thus emphasize the larger events.

A correlation matrix is also computed as part of the multiple regression program. Thus if two of the variables are highly correlated, one can be left out to eliminate the resulting complications in the multiple regression. A correlation value of 0.879 was obtained between the soil moisture reading at 3 in. and the soil temperature. All the rest of the correlations were below 0.800. Some of the other high values were:

M_9 and M_{18}	0.796
$M3$ and M_9	0.780
S and M_9	0.763

All of the rest were below 0.75. Since none were above 0.90, the independent variables were not highly correlated.

An initial set of regressions was run with the discharge as a function of each individual variable and with various combinations of the independent variables. The highest R^2 values (0.52) was obtained using all 9 variables; however, the standadd error of estimate was 122 cfs. By eliminating some of

the variables a smaller standard error was obtained with a slight decrease in the correlation coefficient. The equation of best fit is

$$Q = -163.43 + 5.37 A_{12} - 3.99 Mg + 6.08 V$$

The R^2 value is 0.48 and the standard error of estimate is 90 cfs. These are still unsatisfactory values for R^2 and the standard error; but as more data points become available a better correlation should be obtained. Other variables may be added. An analysis of available snow surveys would give an approximation of water available for runoff. A change in temperature or a ratio of A_{12} and A_{24} might be more appropriate than a temperature average, or degree-days may be the most significant temperature factor. Percentage of snow cover might also be a factor to be tried.

Several multiple regressions were tried using the logarithms of the data. The results were not as good as the equation shown above.

VI. RUNOFF EVENTS

(1) Distribution of Events

The runoff events have been divided into rainfall events and snowmelt events. An event is defined as the recording of a crest stage peak or a definite rise and fall of the continuous record trace. Rainfall events also include snowmelt accompanied by rainfall, since the division was made only as to the type of precipitation based on temperature and time of year.

The breakdown of runoff events by months is shown in Table VI. Of the total number of events 46% were snowmelt events and 54% were rainfall events.

(2) Distribution of Snow Cover and Land Use

Aerial photographs of the watershed have been obtained for evaluating snow cover and land use. An analysis of the three sets of photos available have made it possible to determine the percent of snow cover and the percent of the area in various land uses. These data are shown in Tables VII and VIII.

TABLE VI - DISTRIBUTION OF RUNOFF EVENTS FROM INITIATION OF CREST STAGE PROJECT THROUGH 1965

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
No. of snow-melt events	1	4	6	3	1					2	1		18
% of snow-melt events	5.6	22.2	33.3	16.7	5.6					11.0	5.6		
No. of rain-fall events				6	5	5	1		1	2	1		21
% of rain-fall events				28.5	23.8	23.8	4.8		4.8	9.5	4.8		

TABLE VII - LAND USE BY PERCENT

Date	Stubble	Summer Fallow	Range Land	Other Cropland
1-28-64	42.2	43.0	8.6	6.2
2-12-65	42.2	43.0	8.6	6.2
2-23-66	42.4	41.7	8.7	7.2

TABLE VIII- PERCENT OF LAND IN VARIOUS USES COVERED WITH SNOW

Date	Stubble	Summer Fallow	Range Land	Other Crop Land	Total
1-28-64	97.3	18.9	66.6	84.9	60.1
2-12-65	100.0	100.0	100.0	100.0	100.0
2-23-66	83.2	65.0	63.6	69.1	72.7

VII UNIT HYDROGRAPH

One of the most frequently used techniques in the prediction of flood magnitudes is the unit hydrograph. The principle of the unit hydrograph, which was first expressed by L. K. Sherman in 1932, is based on the hypothesis that identical storms, with the same antecedent conditions, produce identical hydrographs. Under the unit graph theory all hydrographs resulting from rainfalls of a given duration have the same time base. If the rainfall distribution in the storms is similar with respect to time and area, the ordinates of each hydrograph will be proportional to its respective volume of runoff. The unit graph is the hydrograph resulting from a runoff of 1.00 inch over the entire watershed. Once a unit graph has been perpared, a storm of any size can be considered and a hypothetical hydrograph obtained, so long as the storm is of the same duration as that for which the unit hydrograph was prepared.

Four of the rain storm-induced runoff events which have occurred at Lone

Man Coulee are of sufficient magnitude to warrant analysis by the unit hydrograph. The events for which unit graphs were drawn occurred on May 3, 1964, June 8, 1964, June 17, 1965, and June 25, 1965. Hydrographs and unit graphs for these events are shown in Figures 8,9,10, and 11. These figures also show rainfall histograms obtained from recording raingages on the watersheds.

(1) Event of May 3, 1964

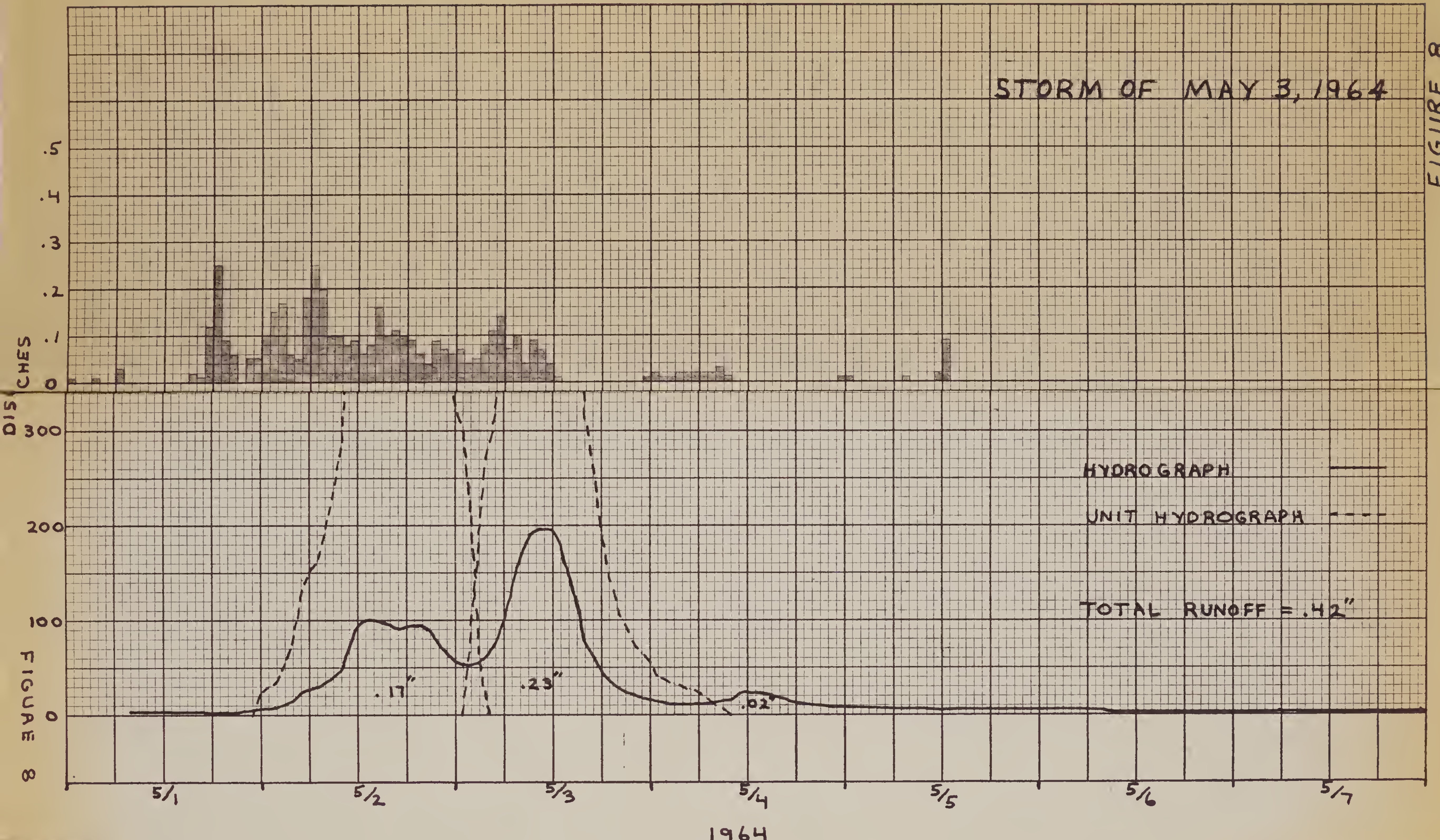
The May 3, 1964 event was the result of a rain storm of between 44 and 45 hours duration. The storm was apparently fairly evenly distributed over the watershed, as evidenced by the rainfall histograms from the Toren ranch (near the mouth of the watershed) and the Geiger ranch (at the headwaters of the watershed).

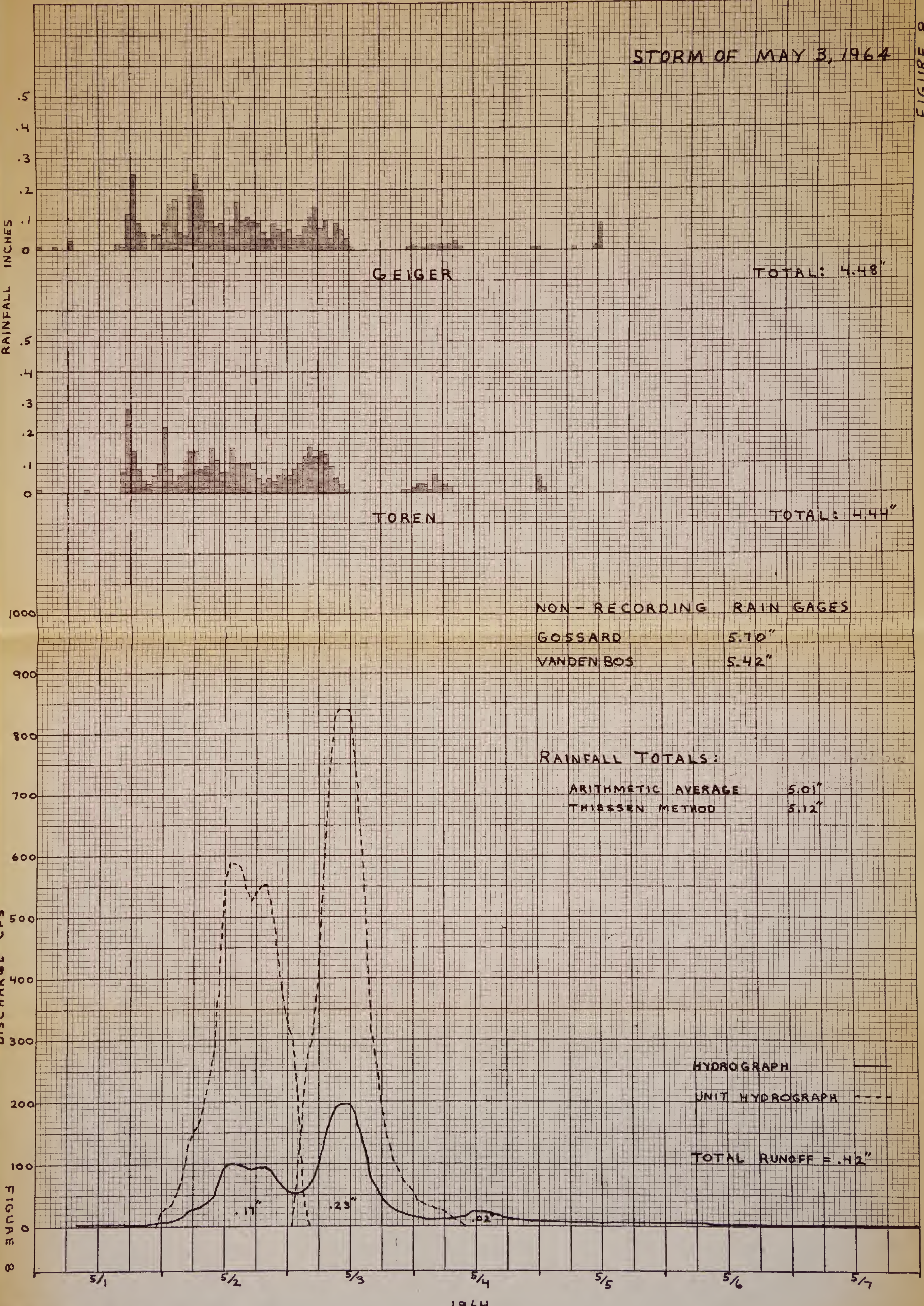
Total rainfall on the watershed was 5.01 inches (arithmetic average from the 4 raingages on the watershed) or 5.12 inches (using the Thiessen method of weighting the stations). Since the hydrograph shows two distinct peaks, the possibility of considering the precipitation as two separate storms, of 28 and 16 hours duration was considered. About 0.40 inch fell sporadically before and after the main storms. 3.85 inches fell during the first 28-hour burst, producing 0.17 inch of runoff, while 0.80 inches of rain fell during the 16-hour burst producing 0.23 inch of runoff.

Since there was no base stream flow prior to the storm, no separation is necessary in construction of the unit hydrograph. As is shown in Figure 8, the unit hydrograph peaks are 590 and 840 cfs.

Basin lag (time from center of mass of rainfall to hydrograph peak) is 10.4 hours for the 1st peak and 11.2 hours for the 2nd peak. Basin lag in each case is less than storm duration time.

Soil moisture measurements are not available for the period preceding the event. However, examination of antecedent precipitation would lead to the assumption that the soil should have been fairly wet at the beginning of the storm. Except for some mixed rain and snow ending April 6, there had been no precipitation until April 22. On that date the watershed received 0.59 inches


STORM OF MAY 3, 1964
HYDROGRAPH
UNIT HYDROGRAPH
TOTAL RUNOFF = .42"
.17"
.23"
.02"
INCHES
DISCHARGE
.5
.4
.3
.2
.1
0
300
200
100
0
5/1
5/2
5/3
5/4
5/5
5/6
5/7
1964
FIGURE 8



STORM OF MAY 3, 1964
RAINFALL INCHES
.5
.4
.3
.2
.1
0
GEIGER
TOTAL: 4.48"
TOREN
TOTAL: 4.44"
NON - RECORDING RAIN GAGES
GOSSARD 5.70"
VANDEN BOS 5.42"
RAINFALL TOTALS:
ARITHMETIC AVERAGE 5.01"
THIESSEN METHOD 5.12"
DISCHARGE CFS
1000
900
800
700
600
500
400
300
200
100
0
HYDROGRAPH
UNIT HYDROGRAPH
TOTAL RUNOFF = .42"
.17"
.23"
.02"
5/1
5/2
5/3
5/4
5/5
5/6
5/7
1964

FIGURE 8

(average of Toren and Geiger gages); April 23, 0.32 inch; April 24, 0.17 inch; April 26, 0.03 inch; April 29, 0,11 inch; April 30, 0.47 inch, for a total of 1.69 inches in the 9 days prior to May 1. None of this April rain produced any runoff.

(2) Event of June 8, 1964

Rain started falling on Lone Man Coulee watershed at 2 p.m. on June 7. (A shower earlier in the day had amounted to less than 0.10 inch). In the 30-hour storm that followed, precipitation was 5.30 inches of rain (arithmetic average from 4 rain gages); 5.20 inches (using the Thiessen method); or 5.33 inches (by constructing isohyets). Although intensity varied from 0.01 inch per hour to 0.61 inch per hour, in general it was fairly steady, averaging about 0.20 inch per hour. Mr. R. A. Dightman, U.S. Weather Bureau, has compared rainfall intensities from several recording stations (including the Geiger station on Lone Man Coulee) located over 100 miles apart, all of which received comparable total amounts of precipitation. He found remarkable agreement, with the several stations each recording nearly identical rainfall patterns, and fairly uniform intensities of 0.20 inch per hour.

The hydrograph for this event (which appears in Figure 9), shows a total runoff of 1.67 inches. Slope area measurements made after the flood showed peak flows of 1460 cfs for Lone Man Coulee and 280 cfs for Miller Coulee, (both determinations made above their confluence a few hundred feet upstream from the water stage recorder). There is no way of knowing whether the two streams peaked at the same time. The water stage recorder showed 2 lesser peaks, at 11 a.m. and 1 p.m.; and the maximum stage at 5 p.m. on June 8. Mr. Williams visited the recorder site at 3:30 p.m. on June 8, and found no evidence at that time that either stream was falling. The 5 p.m. peak registered by the recorder corresponds to the time of failure of the 72-inch culvert immediately upstream from the recorder. A considerable amount of water had been ponded by the culvert, and the peak discharge of 2685 cfs determined by slope area-measurements down-

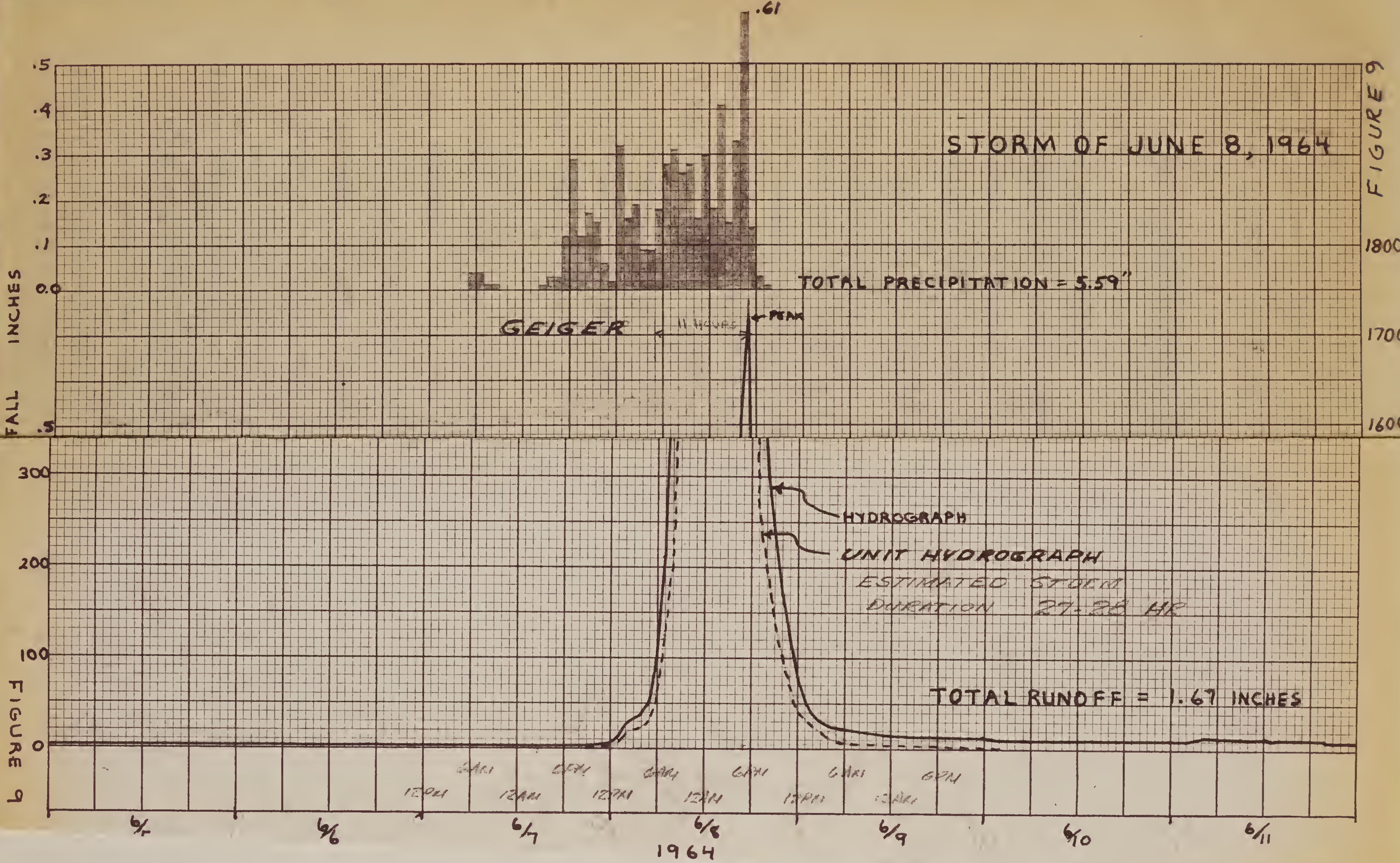

STORM OF JUNE 8, 1964
TOTAL PRECIPITATION = 5.59"
GEIGER
11 HOURS
PEAK
.61
RAINFALL INCHES
.5
.4
.3
.2
.1
0.0
1800
1700
1600
300
200
100
0
HYDROGRAPH
UNIT HYDROGRAPH
ESTIMATED STORM DURATION 27-28 HR
TOTAL RUNOFF = 1.67 INCHES
12PM
6AM
12AM
6PM
6/5
6/6
6/7
6/8
6/9
6/10
6/11
1964

FIGURE 9

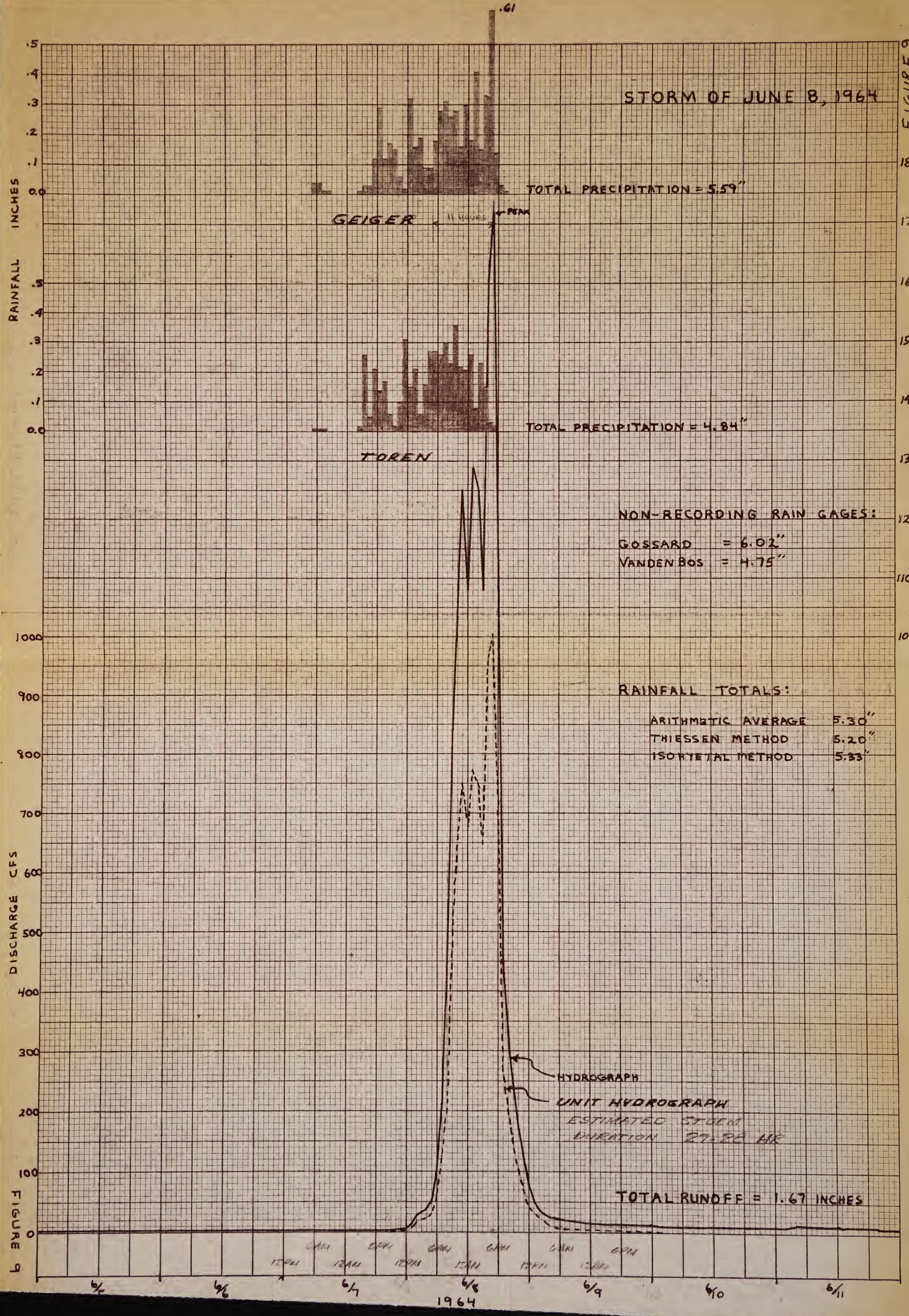


FIGURE 9
STORM OF JUNE 8, 1964
RAINFALL INCHES
.5
.4
.3
.2
.1
0.0
.61
TOTAL PRECIPITATION = 5.59"
GEIGER
PEAK
TOTAL PRECIPITATION = 4.84"
TOREN
NON-RECORDING RAIN GAGES:
GOSSARD = 6.02"
VANDEN BOS = 4.75"
RAINFALL TOTALS:
ARITHMETIC AVERAGE 5.30"
THIESSEN METHOD 5.20"
ISOHYETAL METHOD 5.33"
1800
1700
1600
1500
1400
1300
1200
1100
1000
DISCHARGE CFS
900
800
700
600
500
400
300
200
100
0
HYDROGRAPH
UNIT HYDROGRAPH
ESTIMATED STORM DURATION 27-28 HR
TOTAL RUNOFF = 1.67 INCHES
6/5
6/6
6/7
6/8
6/9
6/10
6/11
1964

FIGURE 9

stream from the recorder reflects the sudden release of the ponded water. From the evidence available, it seems most likely that the two streams peaked simultaneously about 5 p.m., and that the peak discharge was 1460 + 280 or 1740 cfs.

The unit hydrograph constructed for this event has a peak discharge of 1040 cfs.

Basin lag is 11 hours.

Antecedent precipitation studies show that there was no rain between May 11 and May 27. On May 28 there was 0.52 inch and on May 29 there was 0.15 inch. No further rain was reported until June 7. It might be concluded that there was some soil moisture deficiency at the start of the storm on June 7.

(3) Event of June 17, 1965

A series of rain storms on June 15-17, 1965 produced a peak of 110 cfs on June 17. Although the intensity varied greatly with time, the rain was very evenly distributed over the watershed. The first 7-hour burst left 0.88 inch at the Geiger station, and 0.89 inch at the Toren station. Eight hours after the first storm, a second 11-hour storm began, this time recording 1.34 inches at the Geiger station and 1.38 inches at Toren's. This storm was followed by a 2-hour break, after which a 3rd storm left 0.22 inch at Geiger's and 0.40 inch at Toren's.

Total rainfall for the 35 hour period was 2.45 inches (arithmetic average from 4 raingages), or 2.42 inches (Thiessen method). Omitting the first 7-hour storm, the precipitation was 1.67 inches (average of Toren and Geiger stations).

Separation of hydrographs for the individual bursts has not been attempted. The hydrograph for these storms (Figure 10) indicates a total runoff of 0.17 inch. The unit hydrograph has a peak of 650 cfs. Base flow of 3 cfs preceding the storm was subtracted out.

Basin lag, if the first seven-hour storm is neglected, is 11.7 hours.

A study of antecedent precipitation showed that the watershed received frequent showers during the first week in June; there was no further precipitation until June 12 when 0.46 inch fell (average of Geiger and Toren gages). There

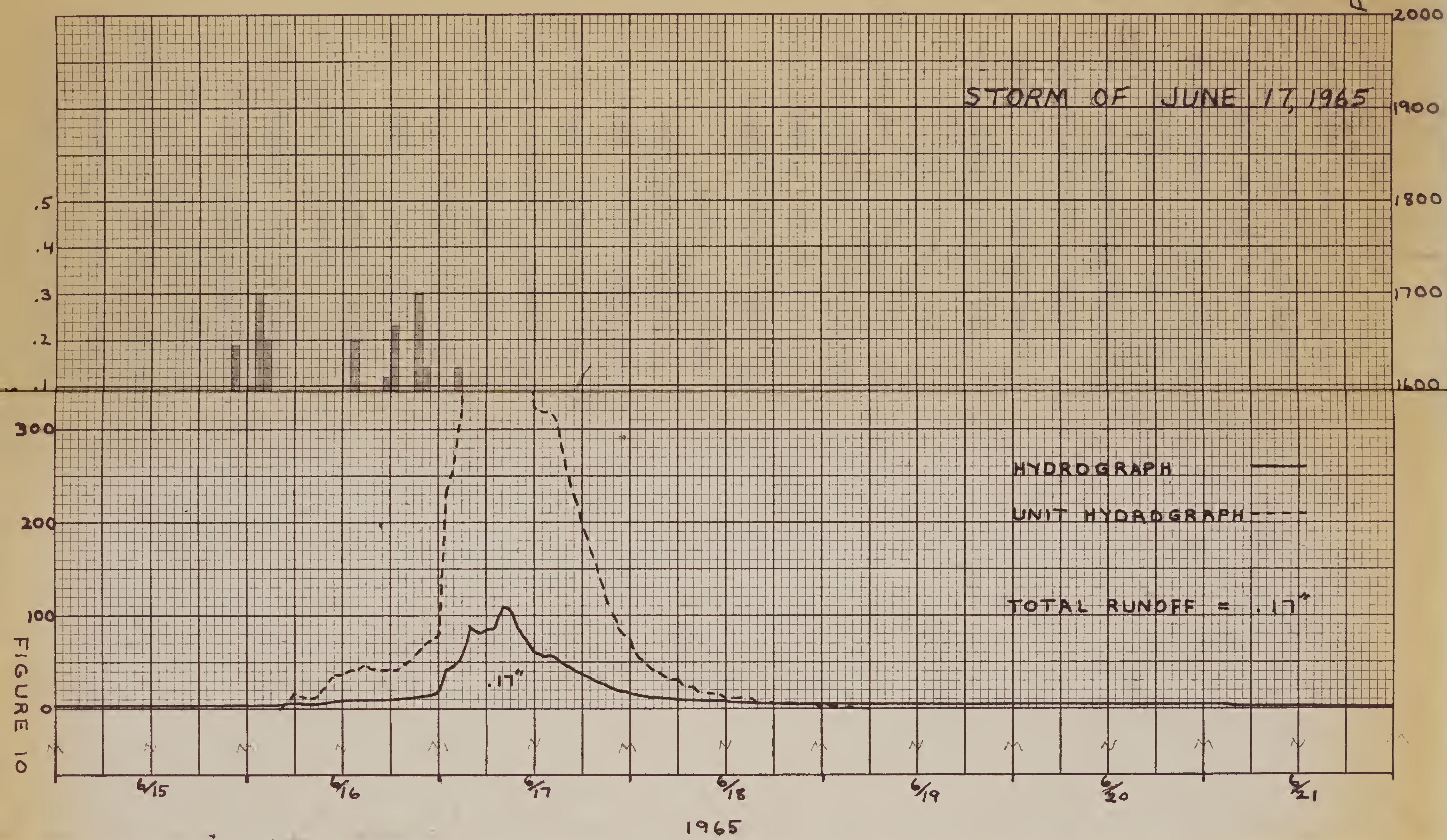


FIGURE 10
2000
1900
1800
1700
1600
STORM OF JUNE 17, 1965
.5
.4
.3
.2
.1
300
200
100
0
HYDROGRAPH
UNIT HYDROGRAPH
TOTAL RUNOFF = .17"
.17"
6/15
6/16
6/17
6/18
6/19
6/20
6/21
1965

FIGURE 10

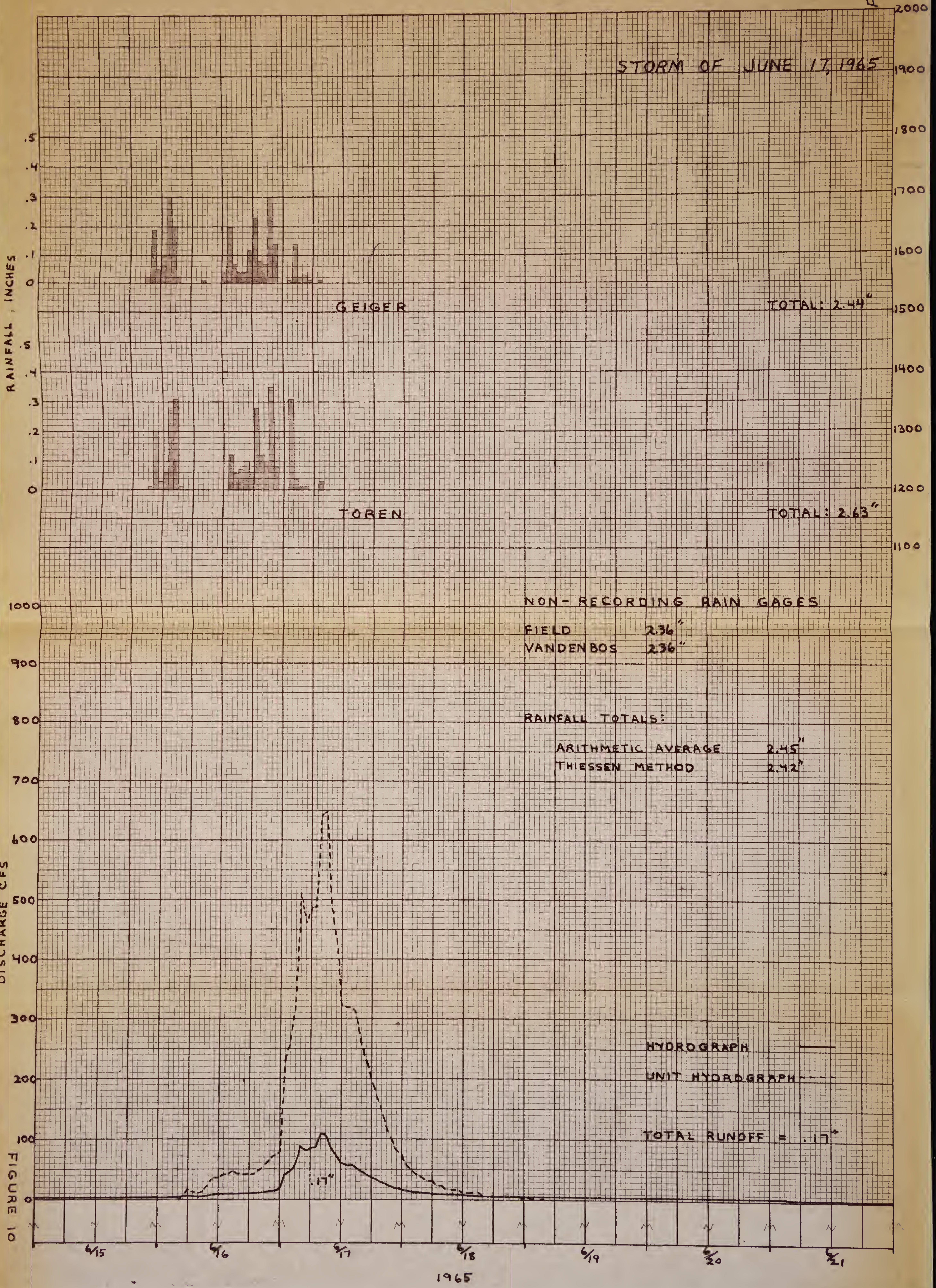


FIGURE 10

FIGURE 10

was 0.10 inch Hune 14. Soil moisture readings are available for the period preceding this event, and are discussed below.

(4) Event of June 25-26, 1965

Rain falling in several short bursts produced two peak discharges, on June 25 and June 26, 1965. The first burst at the Geiger ranch produced 0.64 inch of rainfall in one hour. The total rainfall, spread over a 49-to 53-hour period, was 1.94 inches (average of 4 stations), or 1.82 inches (Thiessen method). Considering the 1st storm as starting at noon on the 24th and ending at 2 a.m., on the 25th, 0.69 inch fell (average of Toren and Geiger stations). From 2 a.m. on the 25th, through 6 a.m. on the 26th, 0.78 inch fell.

The hydrograph for this event (Figure 11) shows a total runoff of 0.31 inches, with 0.16 inch in the first rise, and 0.15 inch is the second. Peak discharges of 200 cfs and 65 cfs were recorded. These correspond to unit hydrograph peaks of 1240 and 425 cfs.

In determining the basin lag, precipitation falling between noon on June 24 and 2 a.m. on June 25 (time of the first peak) was considered as the first storm. Basin lag was 9.4 hours. Precipitation falling between 2 a.m. on June 25 and 6 a.m. on June 26 (time of the second peak) was considered as the first storm. Basin lag was 9.4 hours. Precipitation falling between 2 a.m. on June 25 and 6 a.m. on June 26 (time of the second peak) was considered the second storm. Basin lag was 12.8 hours.

The event of June 17, 1965 (which was discussed above) preceded the June 25-26 event by only 8 days. Light showers were reported on June 19, followed by no precipiation until June 23. The Geiger ranch received 0.22 inch during the night of June 23-24. The Field ranch reported 0.32 inch in the 24 hour period ending at noon on June 24. Soil moisture conditions are discussed below.

(5) Soil Moisture Measurements

Soil moisture measurements have been made at the Toren and Geiger weather stations since July 1964. The measured soil moistures together with the recorded rainfall at these two stations is shown in Figures 12 and 13 for the runoff events of June 17, 1965 and June 25-26, 1965.

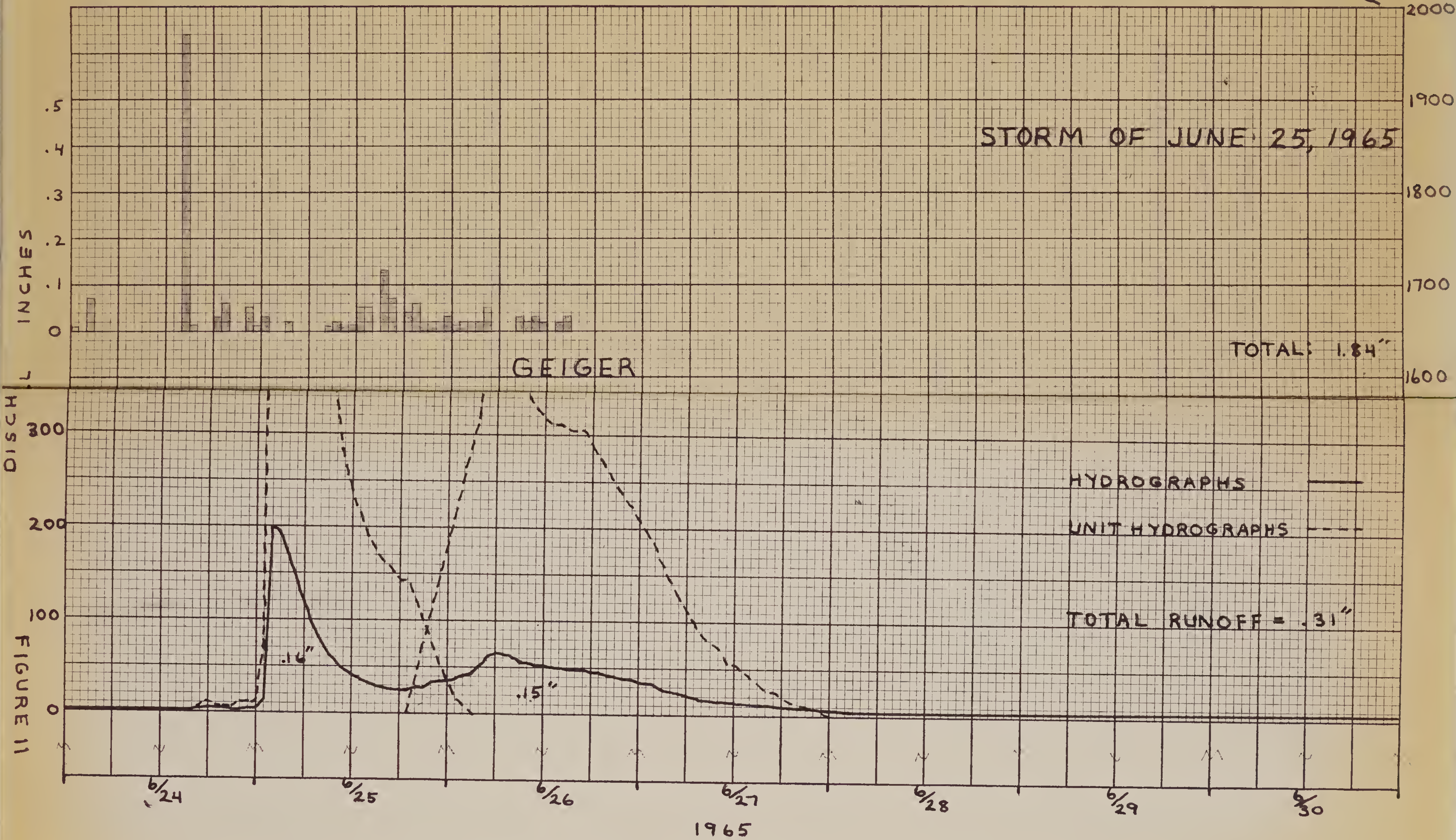
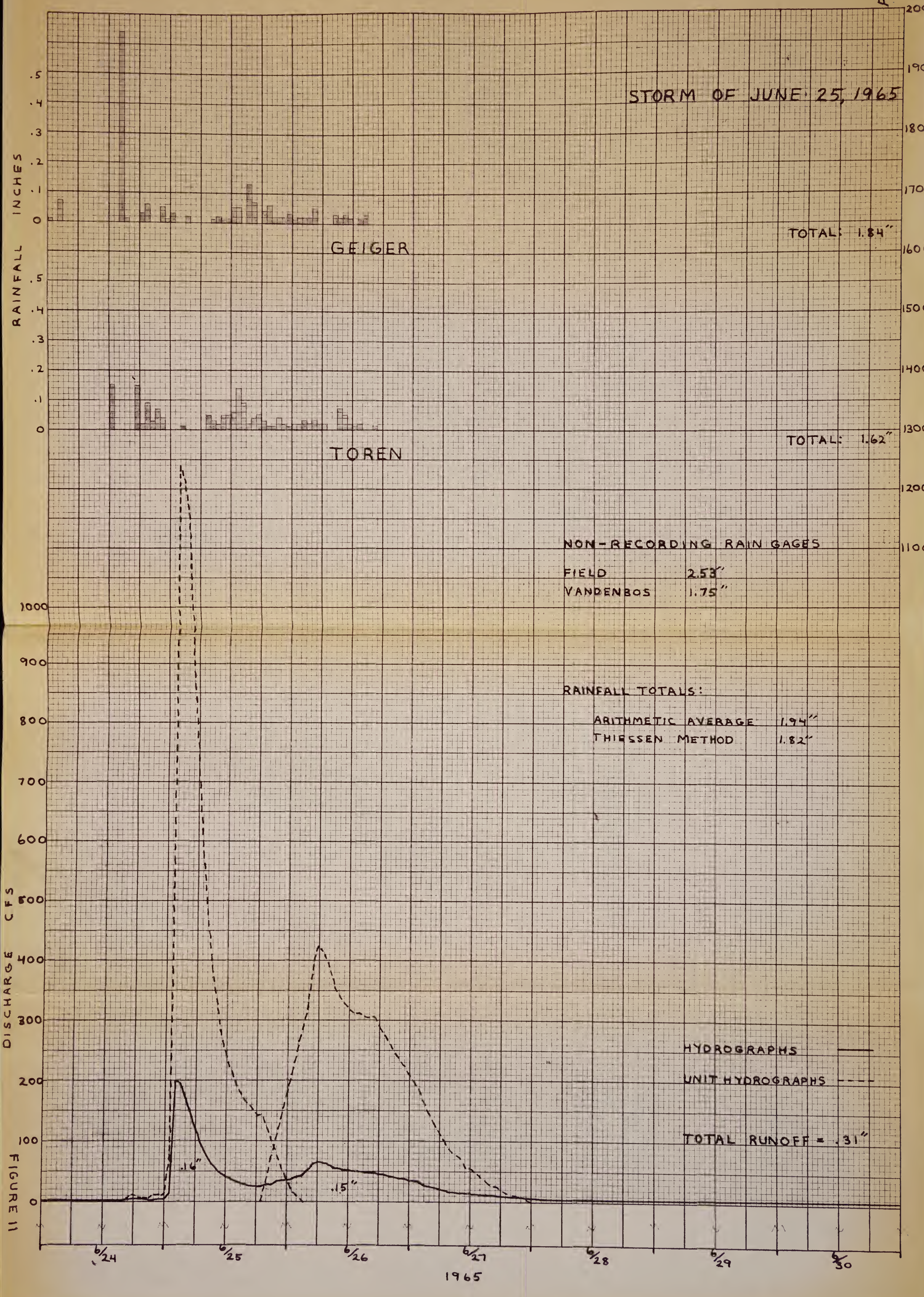

STORM OF JUNE 25, 1965
TOTAL: 1.84"
GEIGER
HYDROGRAPHS
UNIT HYDROGRAPHS
TOTAL RUNOFF = .31"
.16"
.15"
INCHES
.5
.4
.3
.2
.1
0
DISCH
300
200
100
0
2000
1900
1800
1700
1600
6/24
6/25
6/26
6/27
6/28
6/29
6/30
1965

FIGURE 11



STORM OF JUNE 25, 1965
RAINFALL INCHES
GEIGER
TOTAL: 1.84"
TOREN
TOTAL: 1.62"
NON-RECORDING RAIN GAGES
FIELD 2.53"
VANDENBOS 1.75"
RAINFALL TOTALS:
ARITHMETIC AVERAGE 1.94"
THIESSEN METHOD 1.82"
HYDROGRAPHS
UNIT HYDROGRAPHS
TOTAL RUNOFF = .31"
DISCHARGE CFS
.16"
.15"
6/24
6/25
6/26
6/27
6/28
6/29
6/30
1965

FIGURE 11

The soil moisture is measured with gypsum blocks, which require calibration to determine moisture percentage. The calibration curves for the gypsum blocks used are not exact; hence, the values shown in Figures 12 and 13 may not be very accurate, although they are comparable relative to one another. It is relatively safe to assume; however, that the high soil moisture values (20 - 26%) measured after June 15 are near the water holding capacity of the soil.

The soil moisture values correspond well to the precipitation, with low moisture values being recorded during the first part of June when there was little precipitation. The soil during this time was apparently quite dry. On June 16 there occurred a significant rise in the moisture content. This indicates that significant amounts of the precipitation were infiltrated into the soil and did not contribute to runoff. The soil moisture content remained high until the event of June 25-26. For this event there was no evidence of further increase in soil moisture, indicating a small rate of infiltration. The difference in the antecedent soil moisture between these two events is reflected in the ratio of total runoff to total precipitation in Table IX, since less runoff per unit precipitation occurred for the June 16 event in which more infiltration occurred. This soil moisture difference is also reflected in the difference between the peak discharge of the two events.

(6) Discussion of the Unit Hydrographs

As indicated earlier, unit graphs resulting from rainfalls of the same duration are expected to have the same time base and, providing the rainfall distributions are similar with respect to time and area, the ordinates of each hydrograph should be proportional to its respective volume of runoff. Pertinent information from the events described above is summarized in Table IX.

Because of the few events available for study, it is not possible to generalize from the unit graphs that have been produced. The hydrographs from the 28-hour storms have widely varying time bases, and the peak discharges from the unit graphs are vastly different. Less deviation is noted in the two

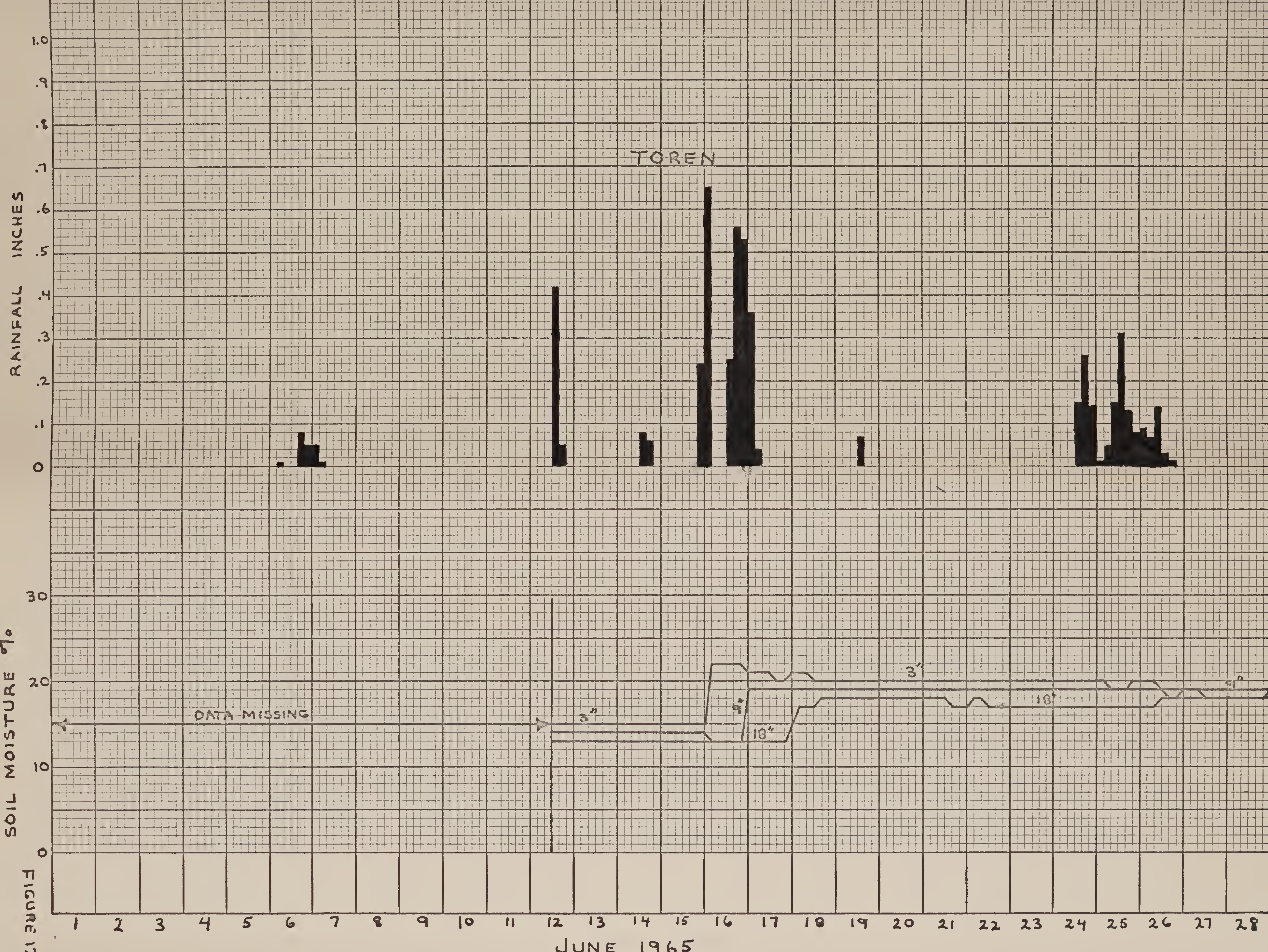

TOREN
RAINFALL INCHES
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
SOIL MOISTURE %
30
20
10
0
DATA MISSING
3"
9"
18"
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
JUNE 1965

FIGURE 12


GEIGER
RAINFALL INCHES
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
SOIL MOISTURE %
30
20
10
0
DATA
MISSING
3"
9"
3"
18"
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
JUNE 1965

FIGURE 13

TABLE IX

Date	Duration of storm hrs.	Time Base for hydrograph hrs.	Basin Lag hrs.	Total Precipitation in.	Volume Runoff in.	Ratio Total Runoff to precip.	Peak discharge, cfs Hydrograph	Unit graph
6-25-65	14	28	9.4	0.69	0.16	0.232	200	1240
6-17-65	16	37	11.7	1.67	0.17	0.102		650
5-3-64	16	33	11.2	0.80	0.23	0.288		840
6-26-65	28	53	12.8	0.78	0.15	0.193	65	425
5-2-64	28	29	10.4	3.85	0.17	0.044		590
6-8-64	28	36	11.0	5.30	1.67	0.315	1740	1040

16 hour storms. Only two of the events could be treated as having resulted from single storms.

To predict flow rates from storms of given magnitude using the unit hydrograph the portion of the precipitation which contributes to runoff must be known. The part of the precipitation which does not contribute to runoff includes interception and depression storage, evaporation, and infiltration into the soil. If these factors can be predicted, the remaining portion must be runoff.

With antecedent soil moisture measurements made for only two events, prediction of infiltration is not possible at this time. Interception and depression storage have not yet been evaluated, but are expected to be quite small in comparison with infiltration. Evaporation is generally a small value also.

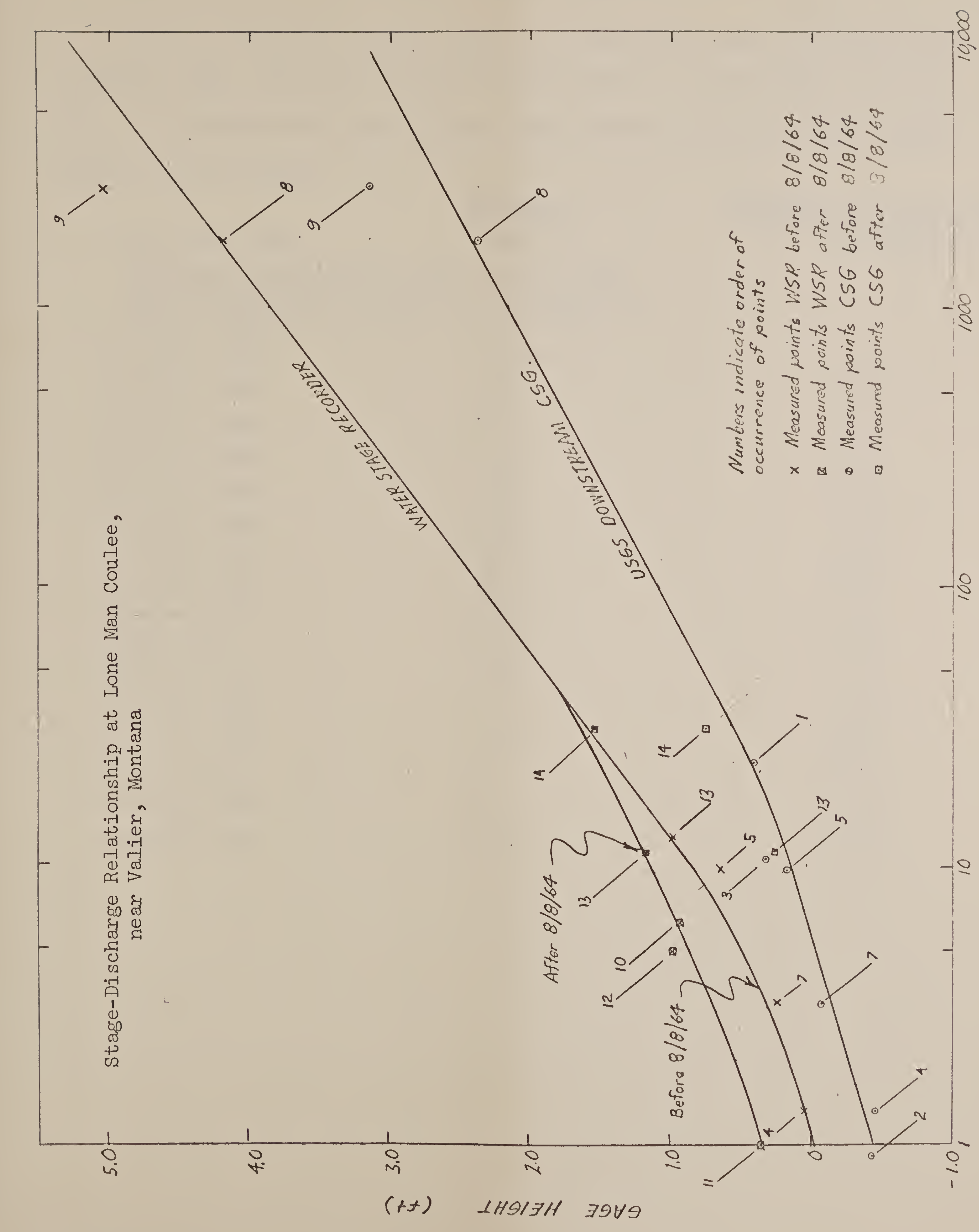
CONCLUSION

This report has considered the analysis of the data collected to date on the Drainage Correlation Research Project at Lone Man Coulee. The frequency analysis of the available data shows promise, although only very rough estimates of the return period of floods of given magnitued can be made. The multiple regression analysis of the data for snowmelt events, showed only unsatisfactory

correlation between peak discharge rate and the correlated variables. There were not enough data available to perform a multiple regression analysis for the rainfall events. The unit hydrograph analysis shows wide variation among the time bases and peak discharges of unit hydrographs derived from various storms. The fact that the basin lag remains relatively constant among these storms reflects the basic soundness of the unit hydrograph technique. The main problem is most likely the lack of runoff events which closely fit the assumptions of the unit hydrograph.

Each technique of analysis applied to the Lone Man Coulee data shows promise in so far as it can be applied. The only apparent problem is that the records obtained to date are not long enough to give results of adequate reliability.

APPENDIX A



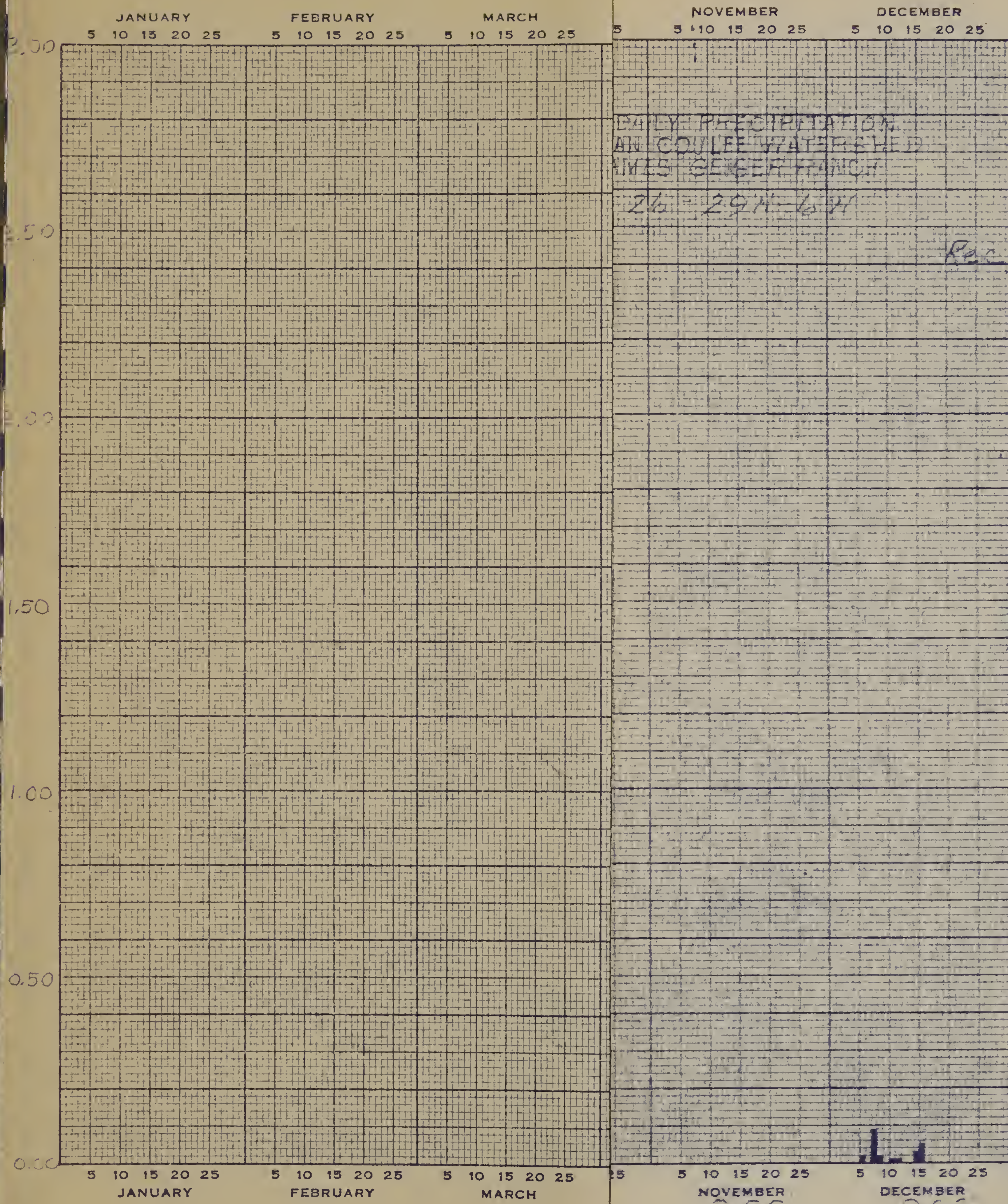
Stage-Discharge Relationship at Lone Man Coulee,
near Valier, Montana
WATER STAGE RECORDER
USGS DOWNSTREAM CSG.
After 8/8/64
Before 8/8/64
Numbers indicate order of occurrence of points
× Measured points WSR before 8/8/64
⊠ Measured points WSR after 8/8/64
⊙ Measured points CSG before 8/8/64
⊡ Measured points CSG after 8/8/64
GAGE HEIGHT (ft)
DISCHARGE (cfs)

APPENDIX B

RUNOFF EVENTS RECORDED AT LONE MAN COULEE

The U. S. Geological Survey installed a crest-stage gage at Lone Man Coulee on May 27, 1959. Peak flows reported by USGS prior to installation, in August 1963, of a continuously recording water stage recorder as part of this investigation, are as follows:

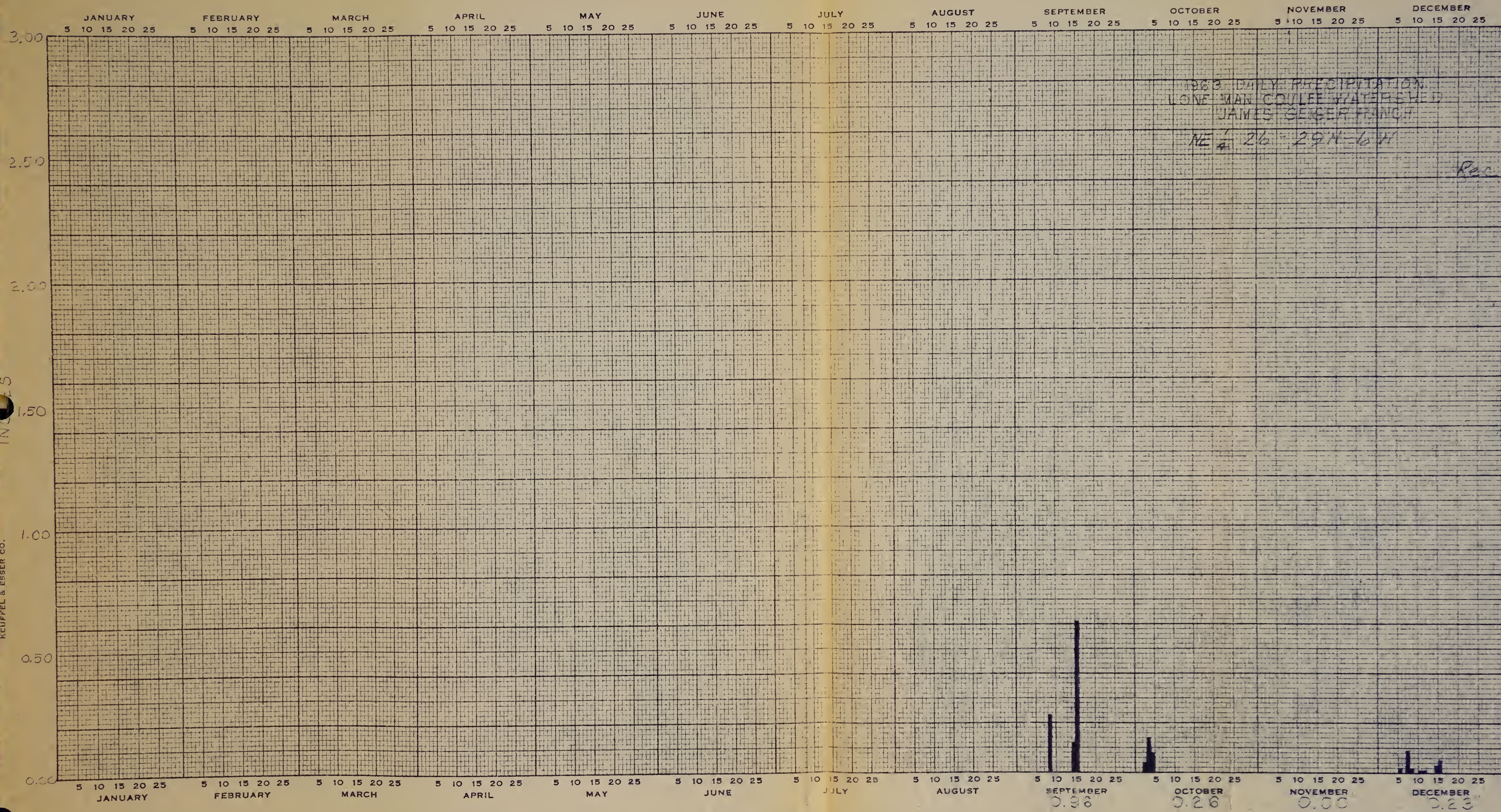
	Discharge	Discharge per square mile
June 16-18, 1948	1820 cfs	160 cfs/sq. mi.
(Slope-area measurement prior to crest stage gage installation; location of measurement not clear - watershed indicated as 11.4 sq mi)		
June 26, 1959	20.2 cfs	1.43
June 27, 1959	18.5	1.31
Nov. 21, 1959	17	1.21
Mar. 17, 1960	23.4	1.66
Mar. 18, 1960	23.7	1.68
Mar. 19, 1960	23.7	1.68
Mar. 20, 1960	28	1.98
Mar. 26, 1960	10.5	0.74
May 1, 1960	31.5	2.24
May 17, 1961	21.5	1.52
Jan. 29, 1962	15	1.06
Jan. 30, 1962	10.3	0.73
Feb. 3, 1963	20	1.42
Mar. 27, 1963	24	1.70
Aug. 19, 1963	27.2	1.93



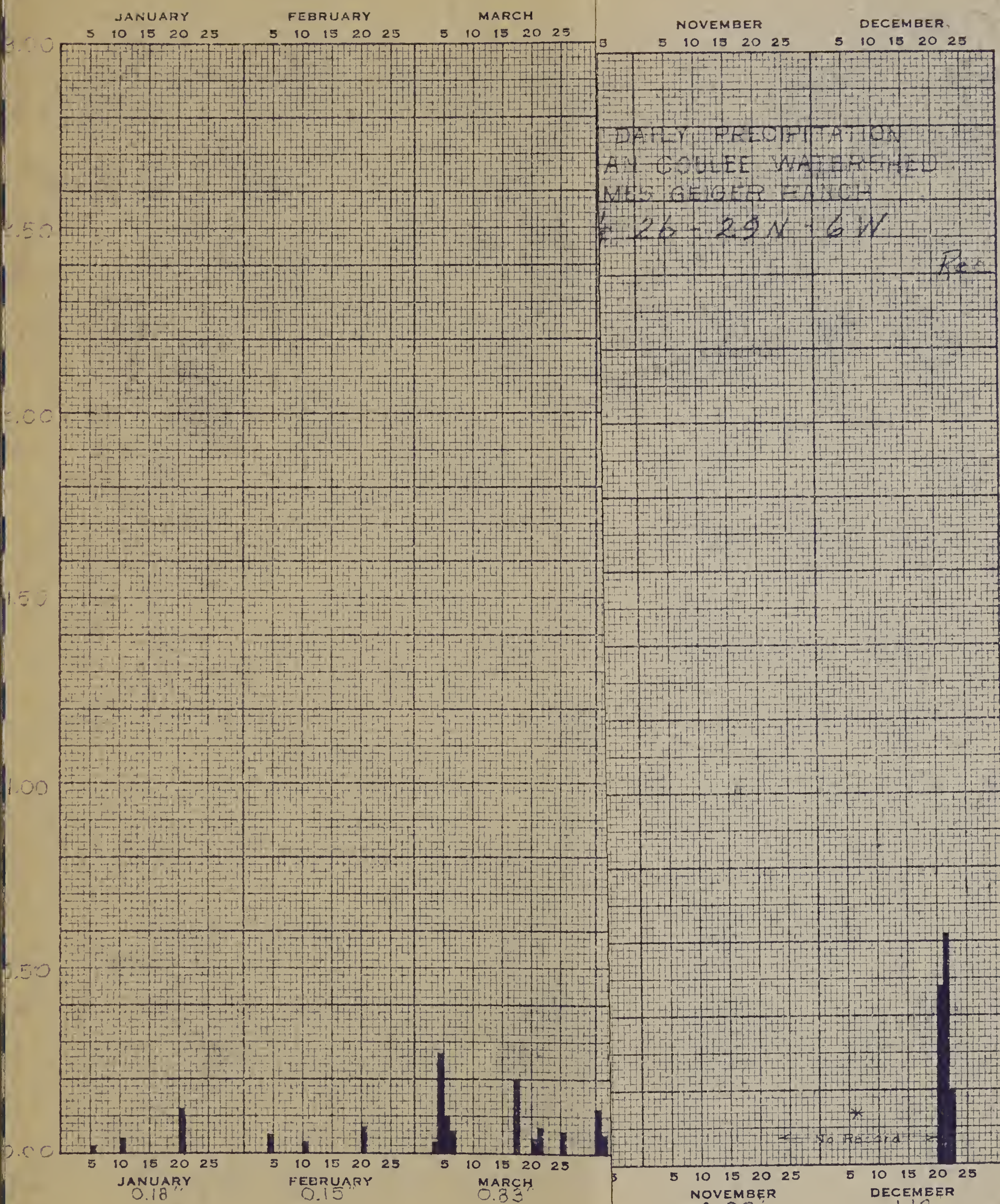
0.00

0.23

TOTAL: 1.45
SEPT.–DEC.
1963

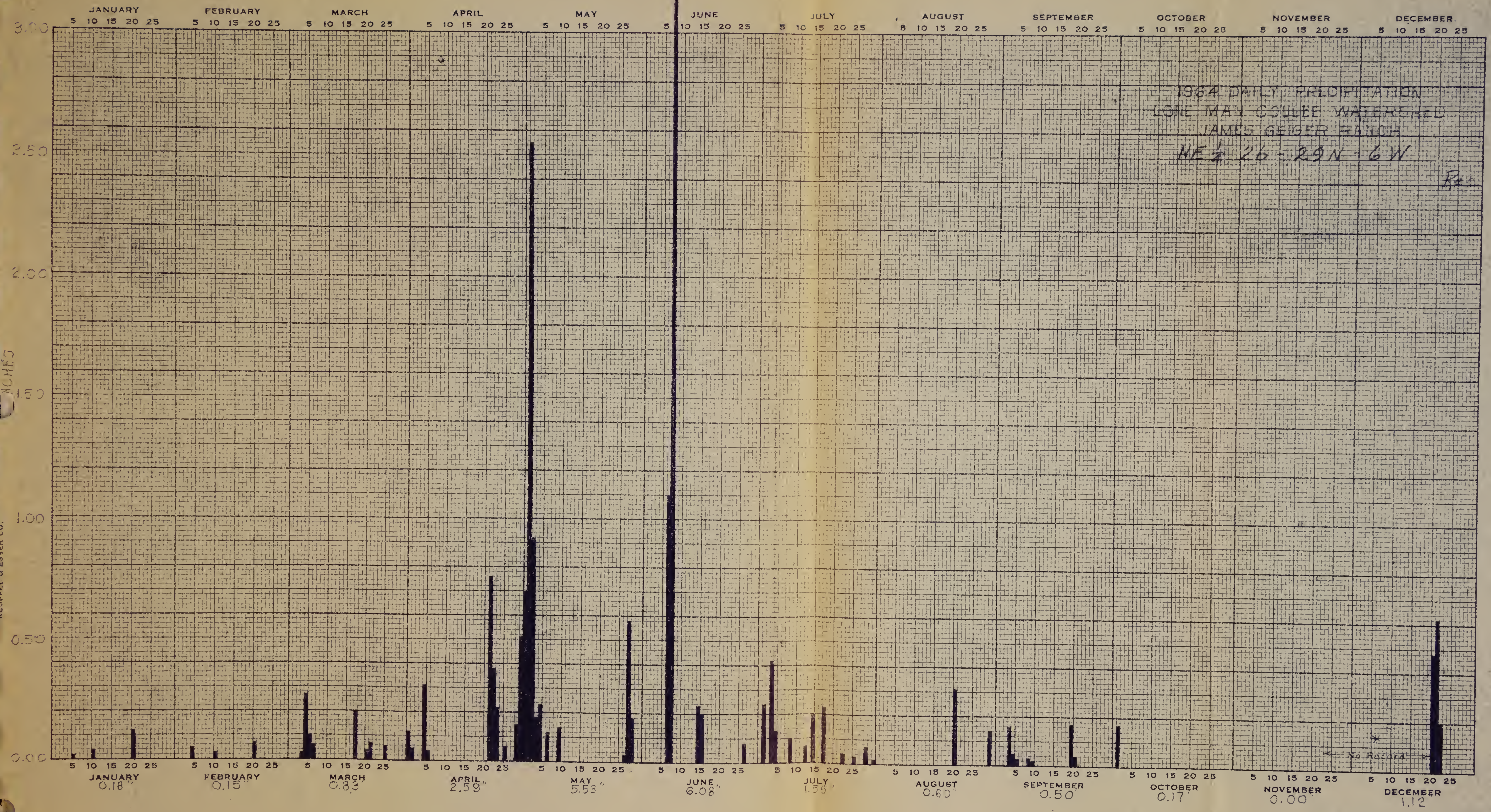


TOTAL: 1.45
SEPT.—DEC.
1963



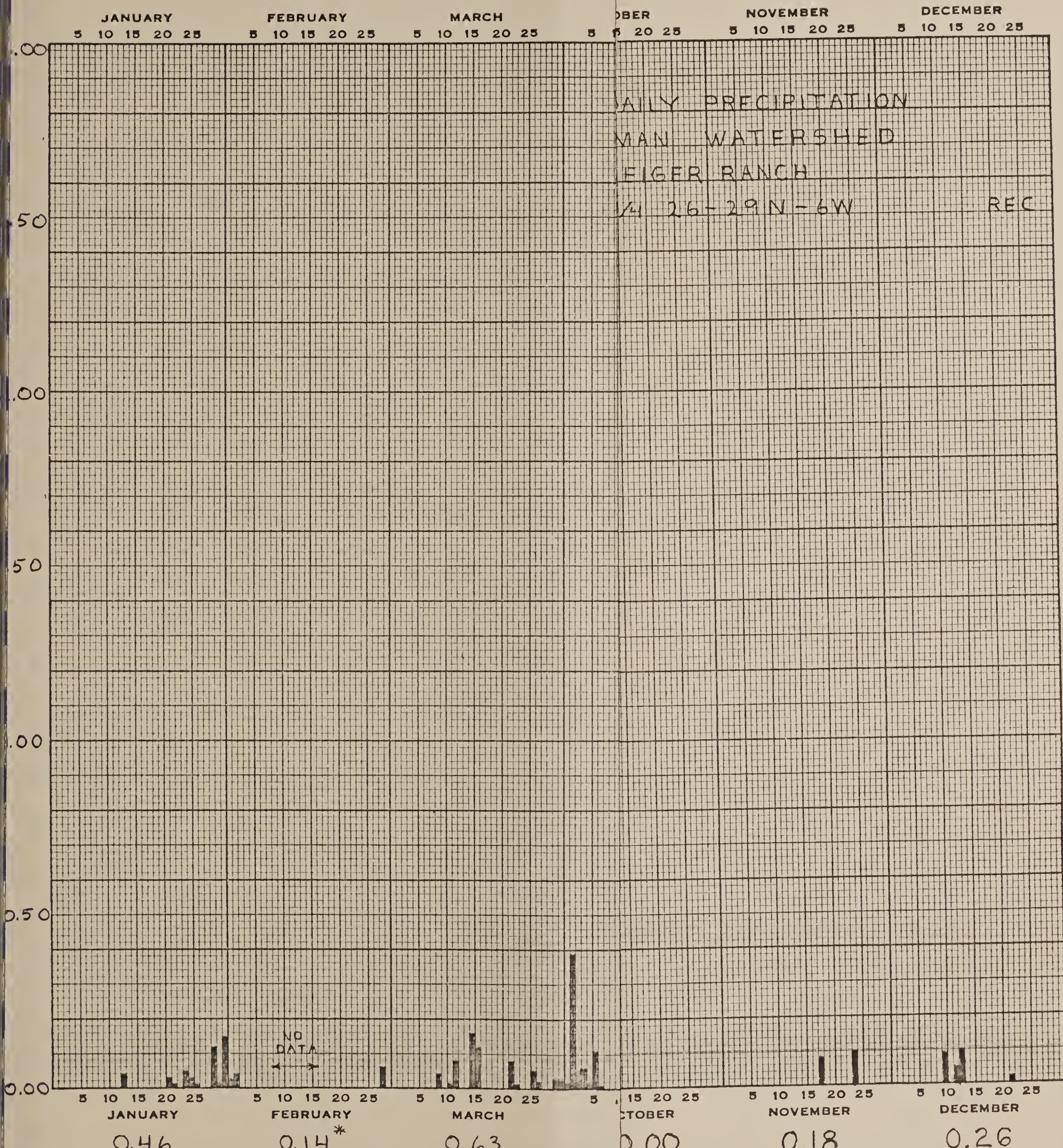
* TOTAL: 19.30"

1964

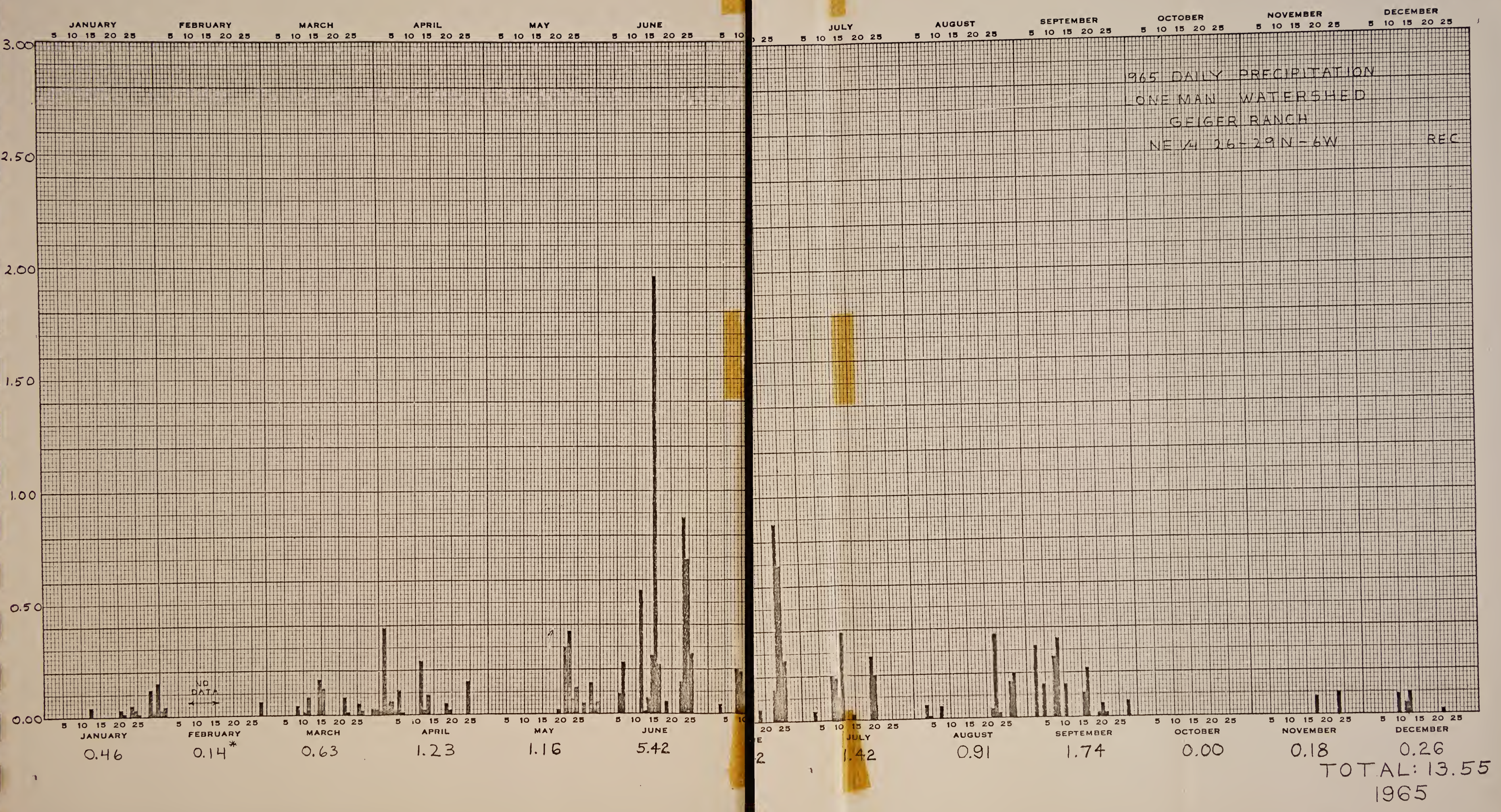


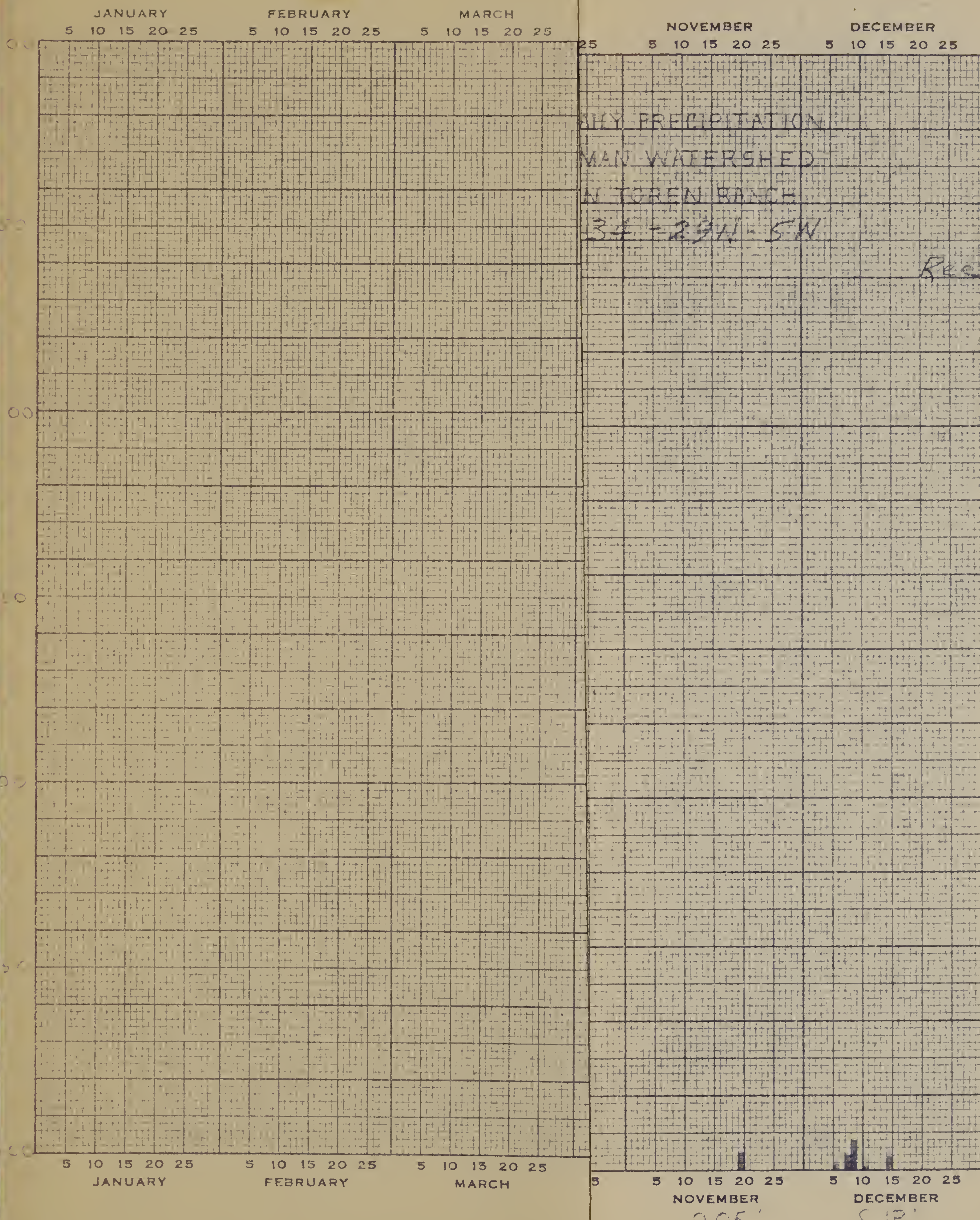
* TOTAL: 19.30"

1964

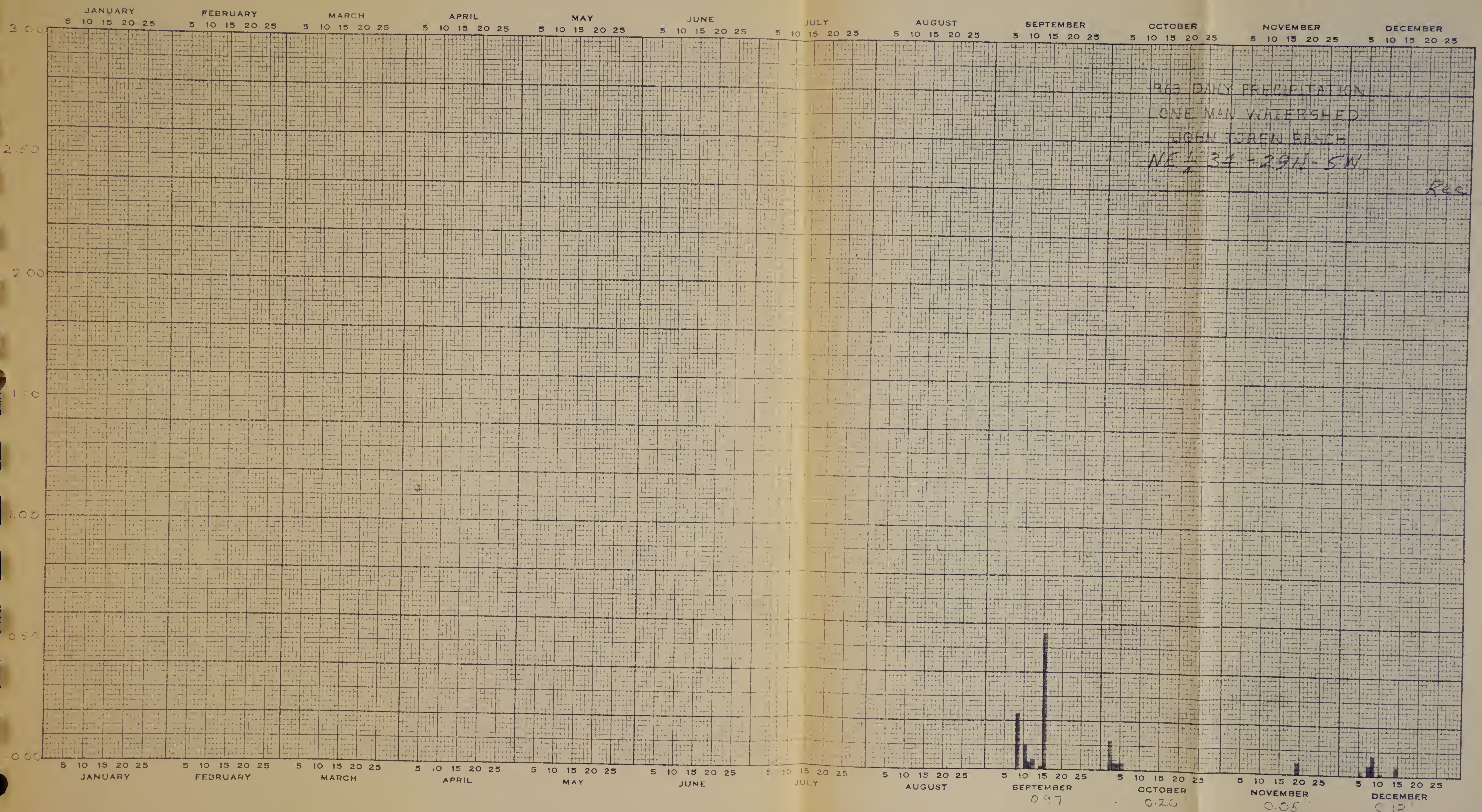


TOTAL: 13.55
1965

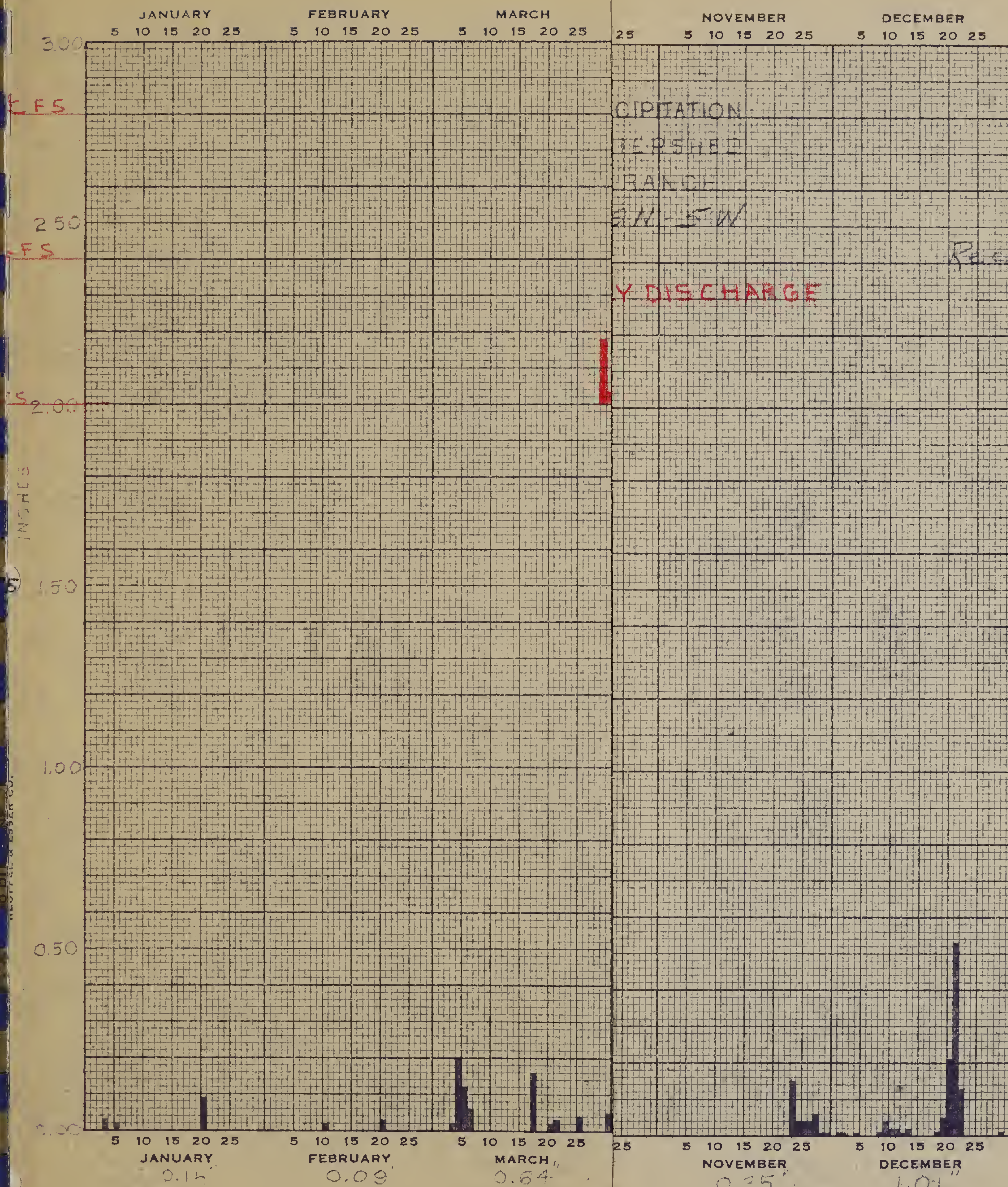

965 DAILY PRECIPITATION
LONE MAN WATERSHED
GEIGER RANCH
NE 1/4 26-29N-6W
REC
3.00
2.50
2.00
1.50
1.00
0.50
0.00
NO DATA
JANUARY 0.46
FEBRUARY 0.14*
MARCH 0.63
APRIL 1.23
MAY 1.16
JUNE 5.42
JULY 1.42
AUGUST 0.91
SEPTEMBER 1.74
OCTOBER 0.00
NOVEMBER 0.18
DECEMBER 0.26
TOTAL: 13.55
1965



TOTAL 1.40
SEPT.-DEC 1963

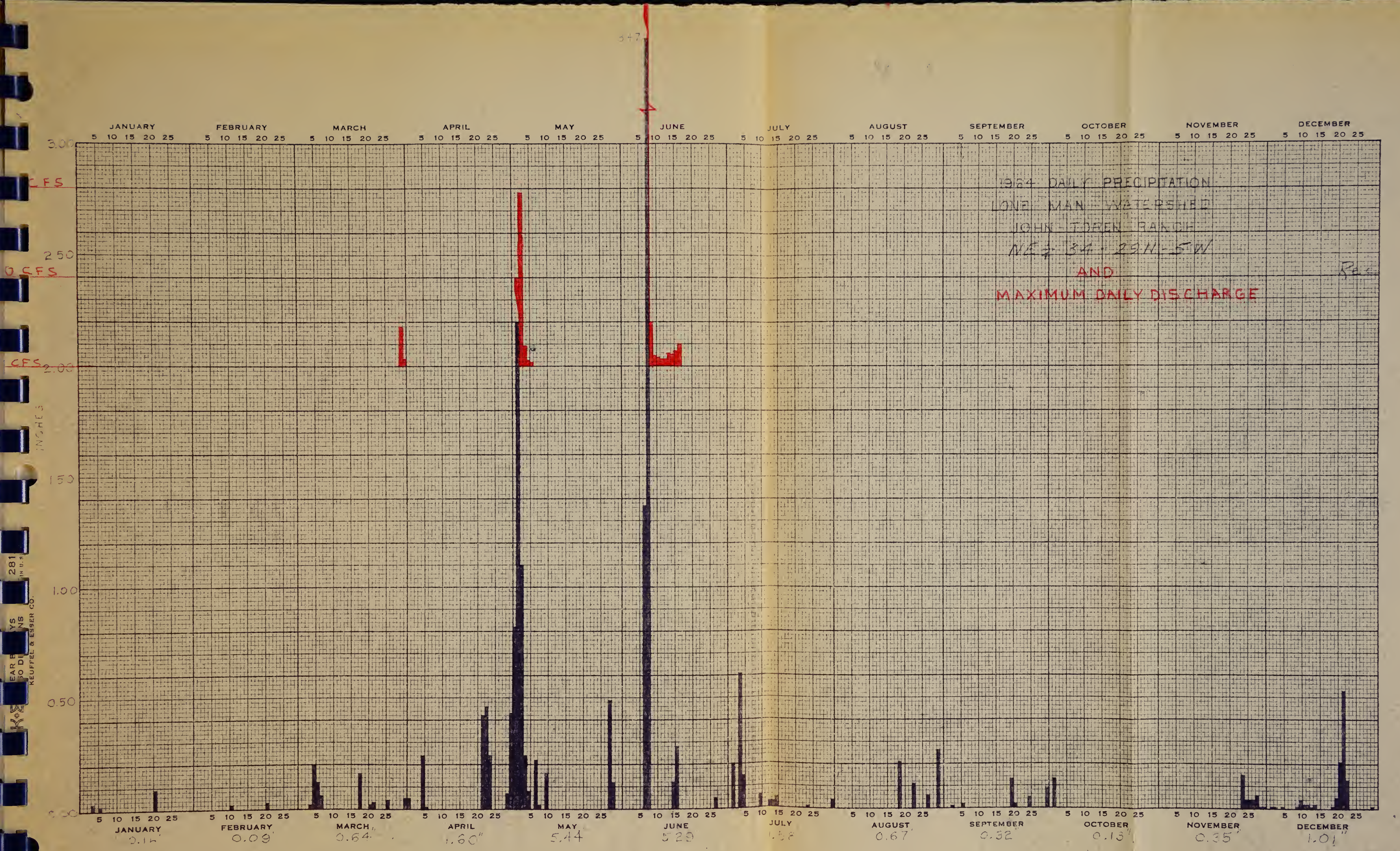


TOTAL 1.40
SEPT.-DEC 1963

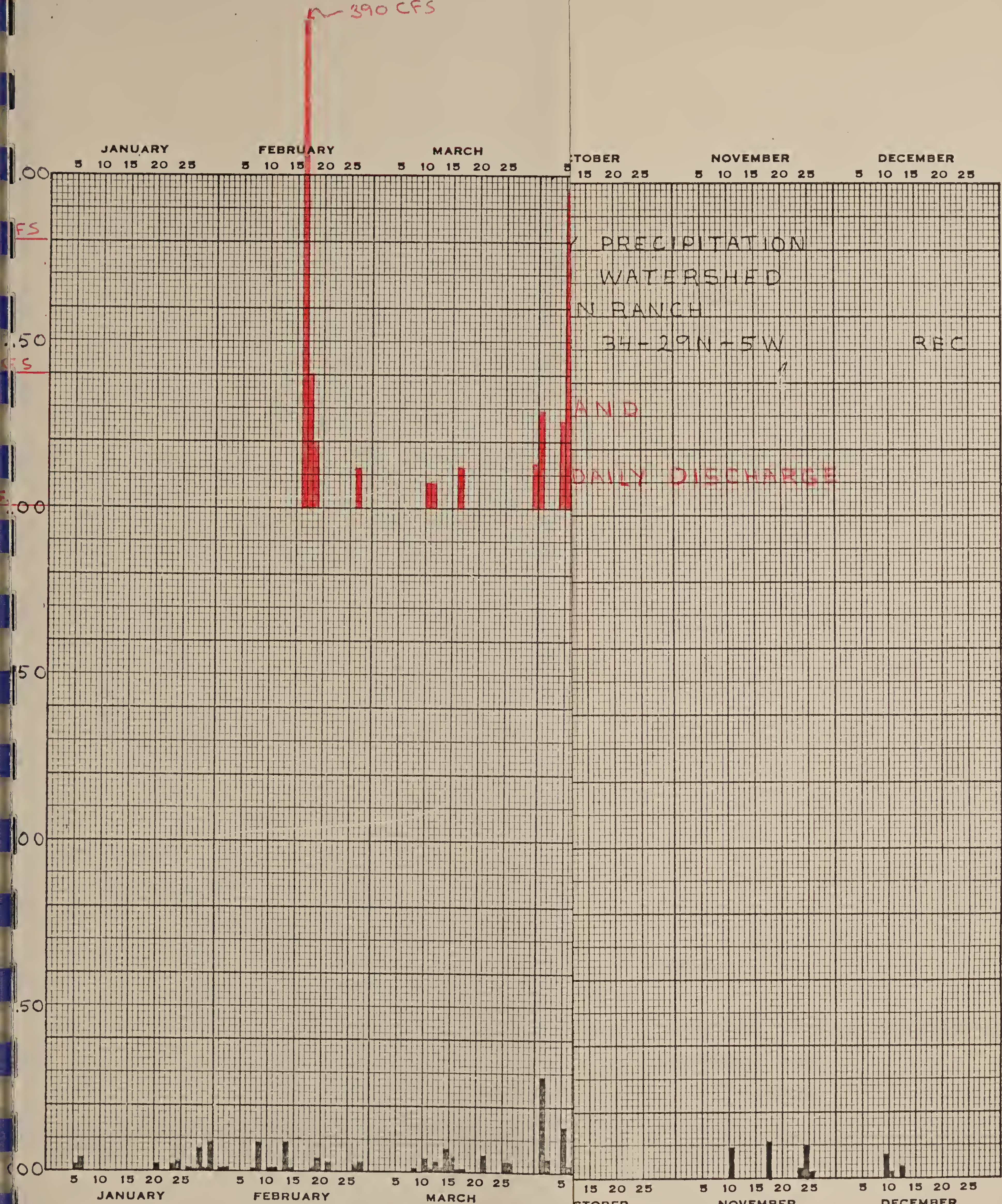


TOTAL: 17.26"

1964



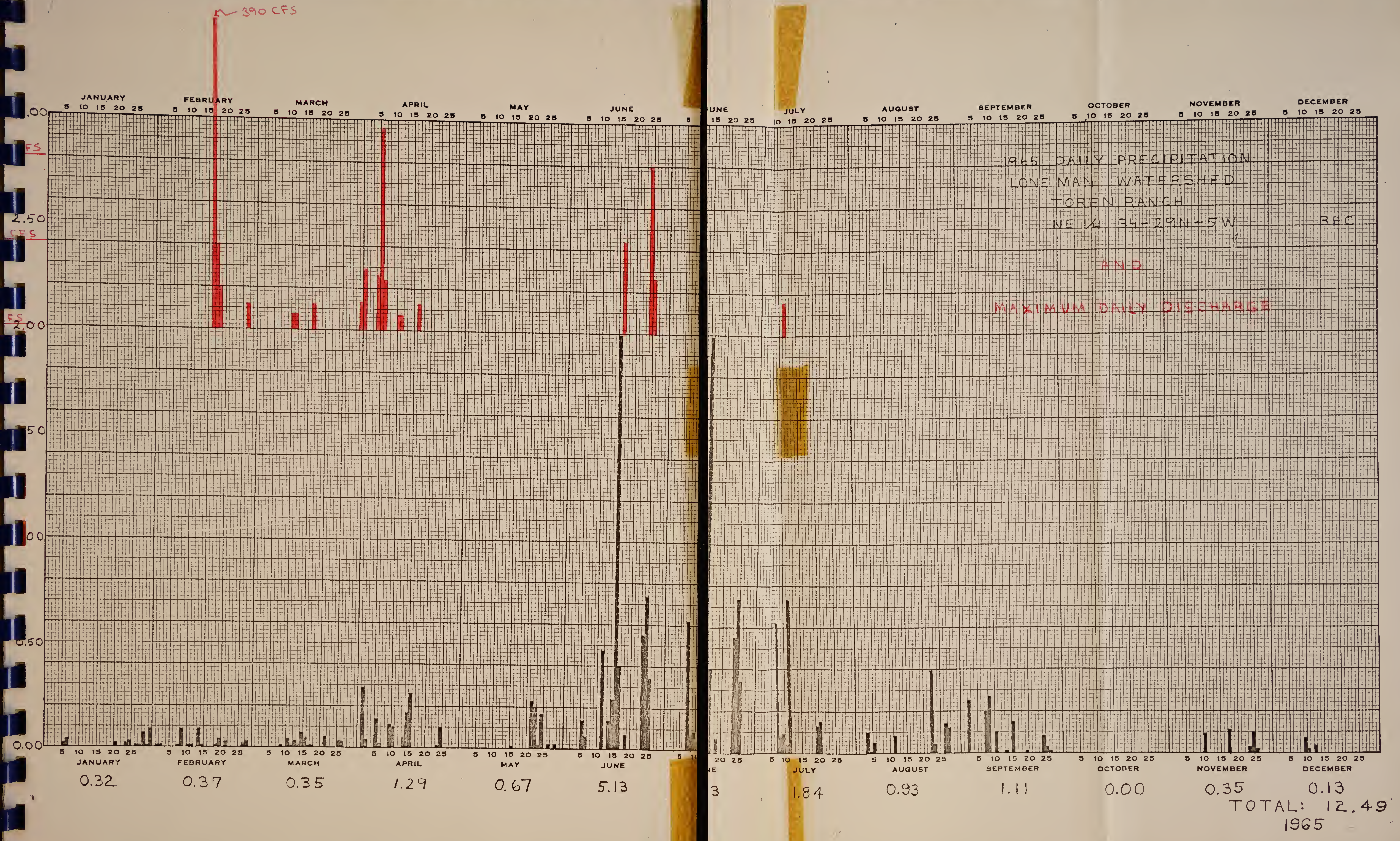
TOTAL: 17.26"
1964

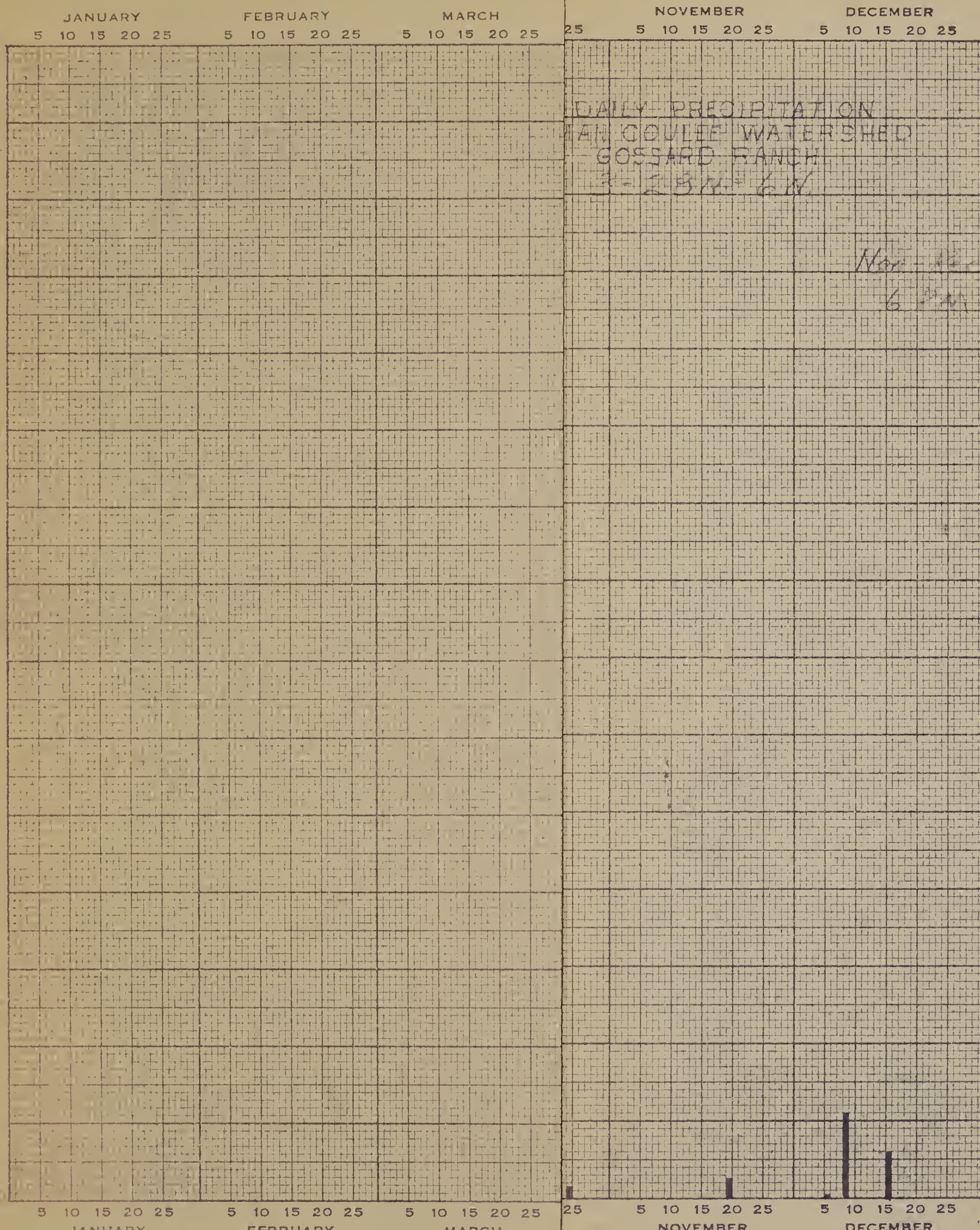


0.32 0.37 0.35 0.00 0.35 0.13

TOTAL: 12.49

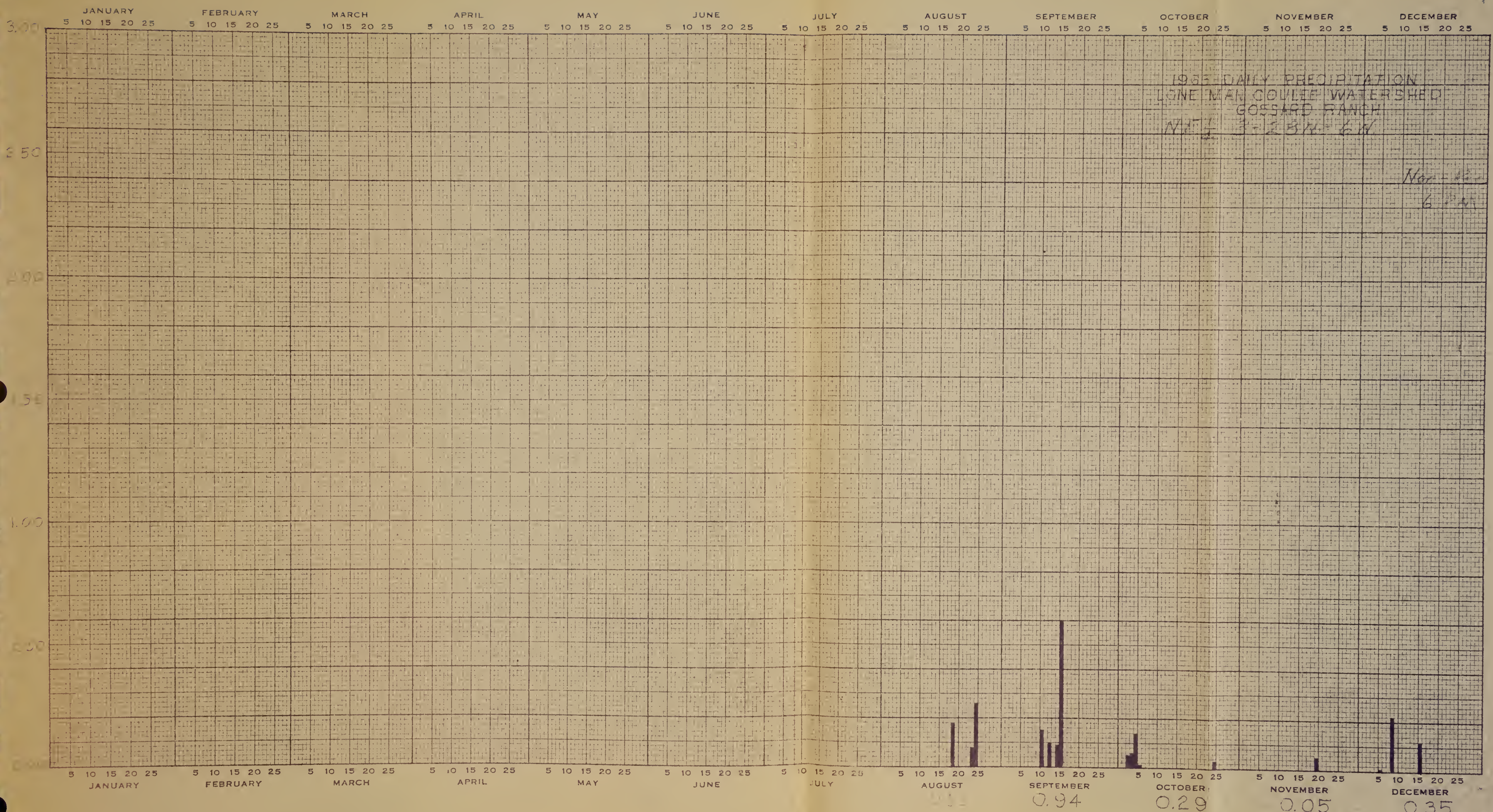
1965


1965 DAILY PRECIPITATION
LONE MAN WATERSHED
TOREN RANCH
NE 1/4 34-29N-5W
REC
AND
MAXIMUM DAILY DISCHARGE
390 CFS
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
5 10 15 20 25
2.50
2.00
0.50
0.00
0.32
0.37
0.35
1.29
0.67
5.13
1.84
0.93
1.11
0.00
0.35
0.13
TOTAL: 12.49
1965

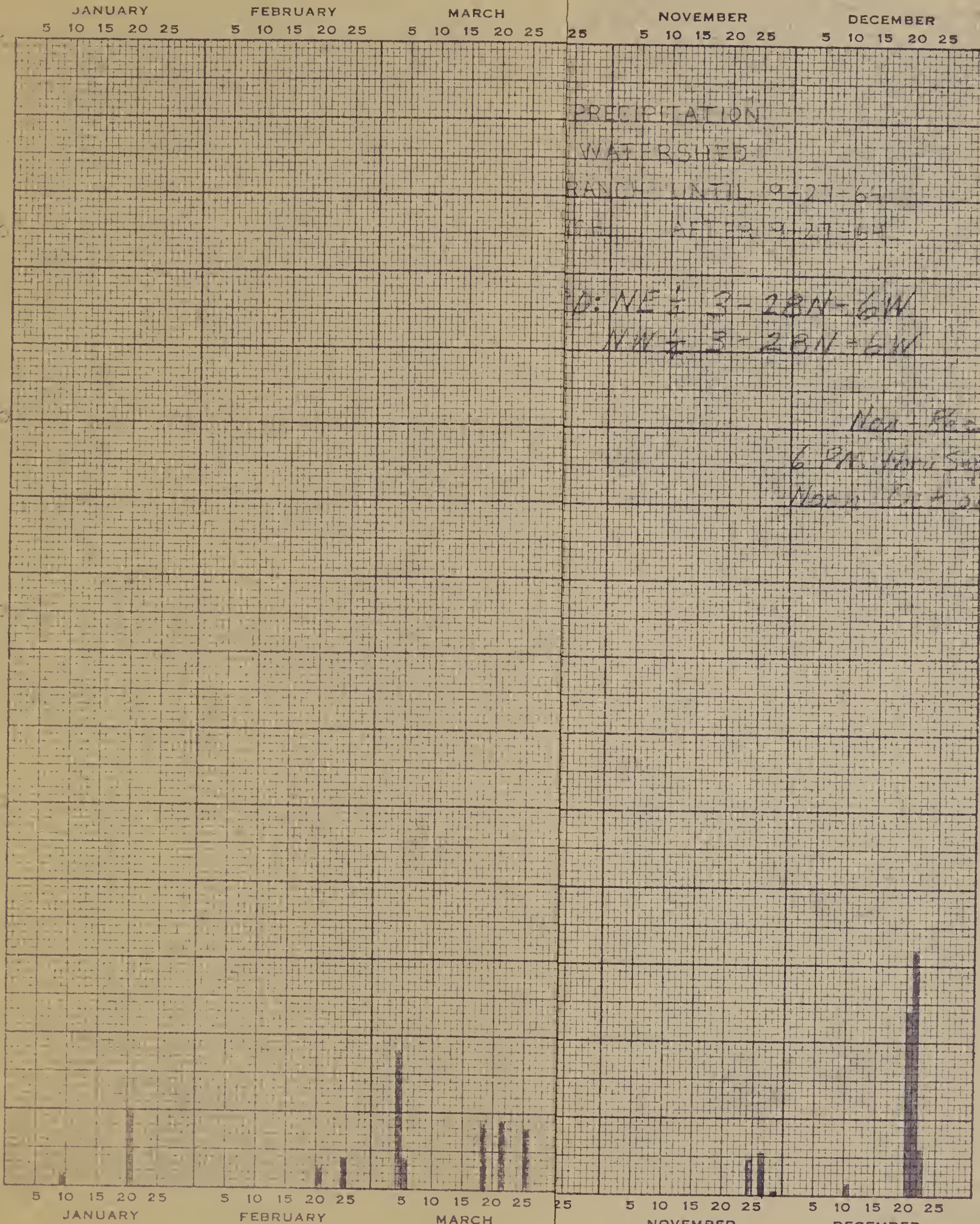


0.05 0.35

TOTAL: 2.15
AUG - DEC. 1963

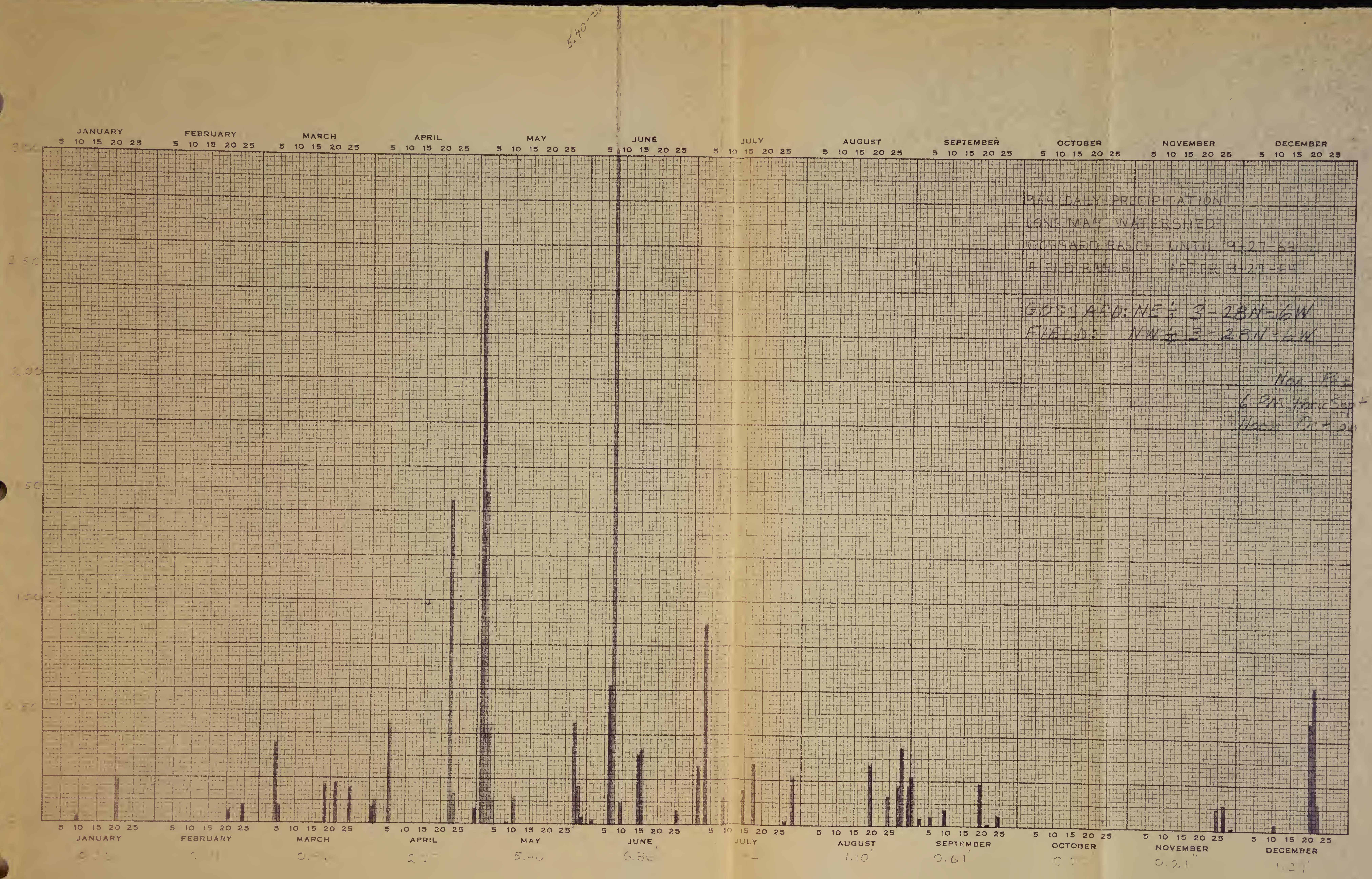


TOTAL: 2.15"
AUG - DEC. 1963



TOTAL: 20.99

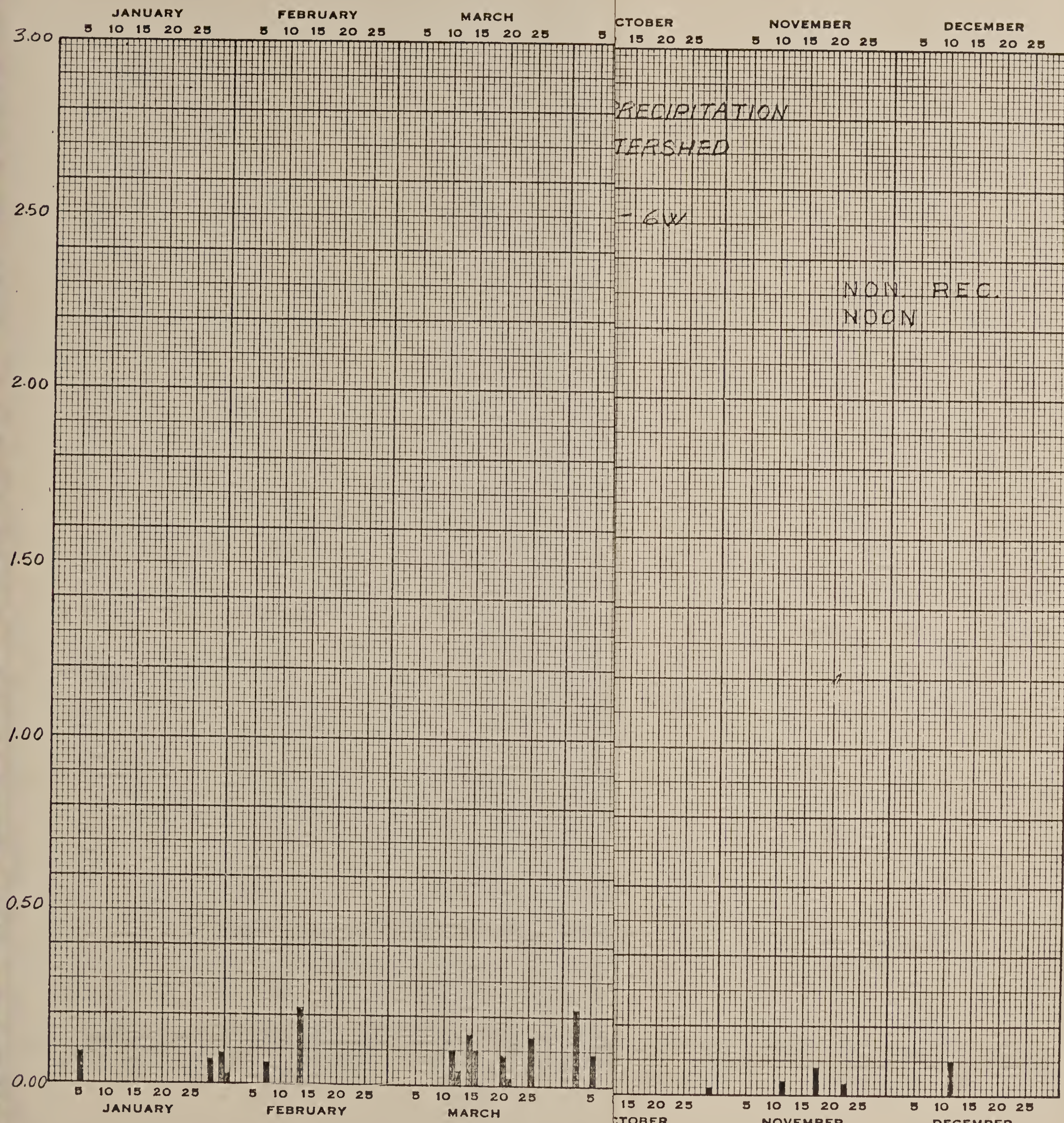
1964



5.86 1.10 0.61 0.21

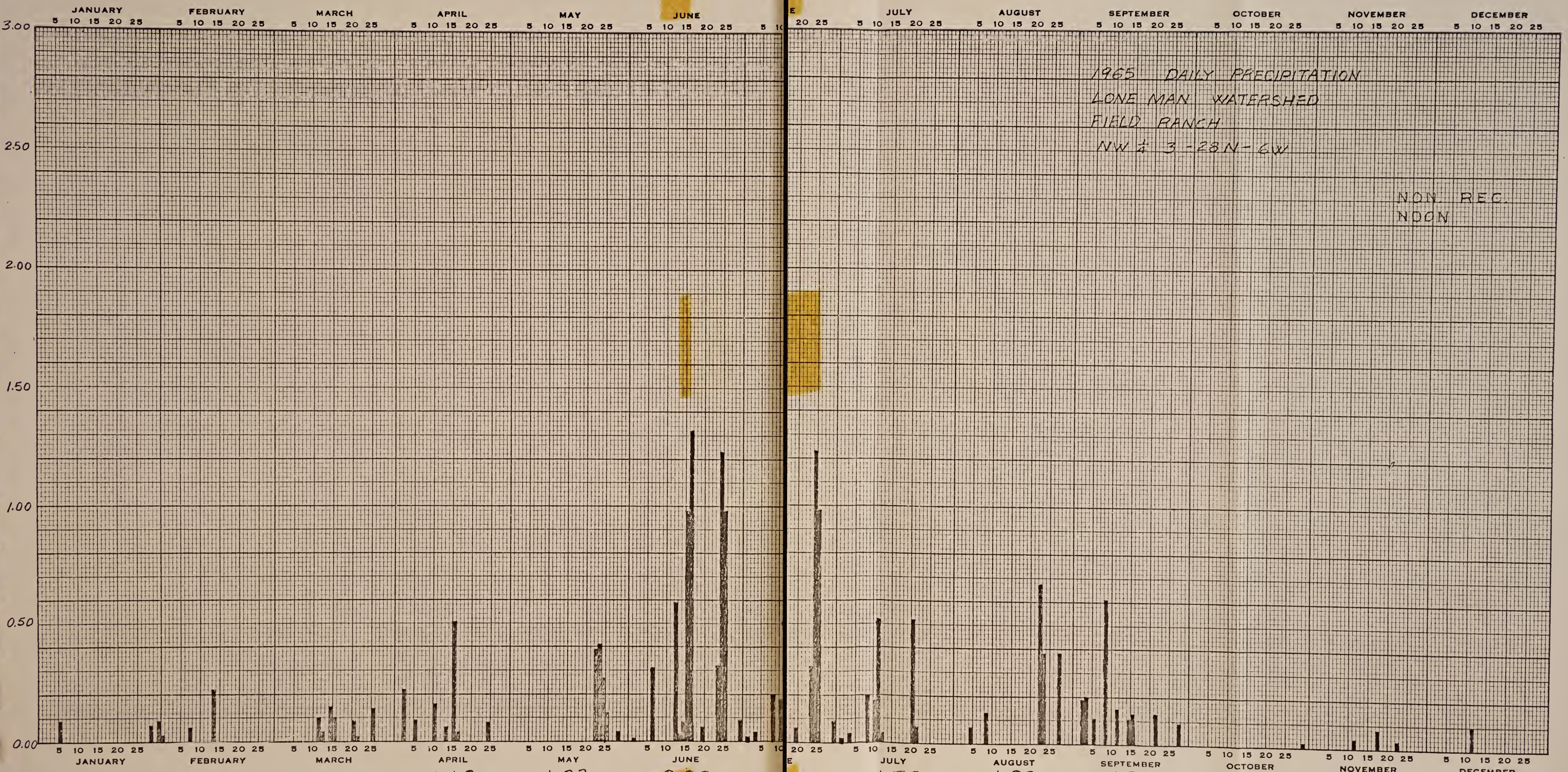
TOTAL: 20.99"

1964



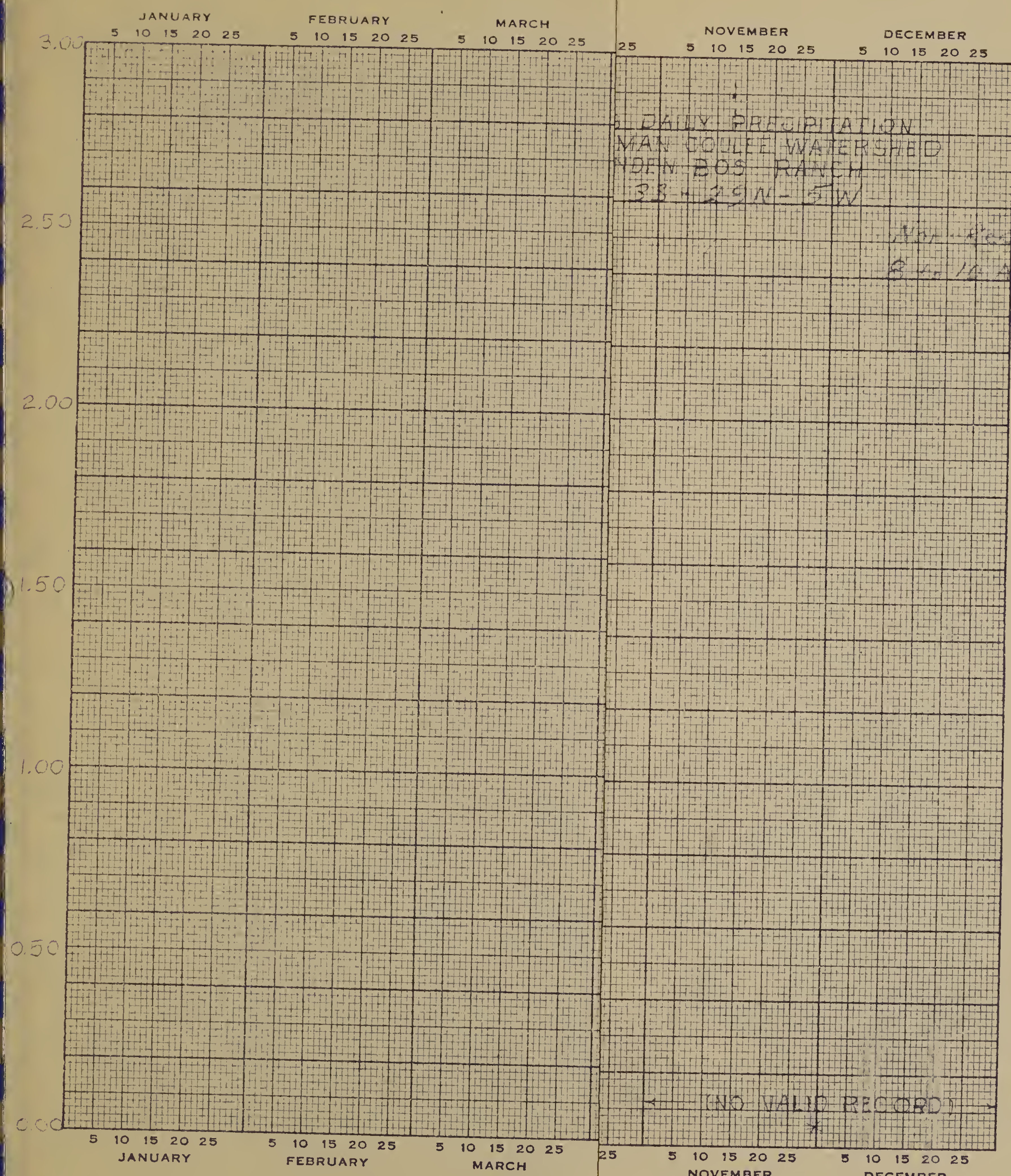
0.25 0.31 0.64).02 0.15 0.10

TOTAL: 14.80
1965

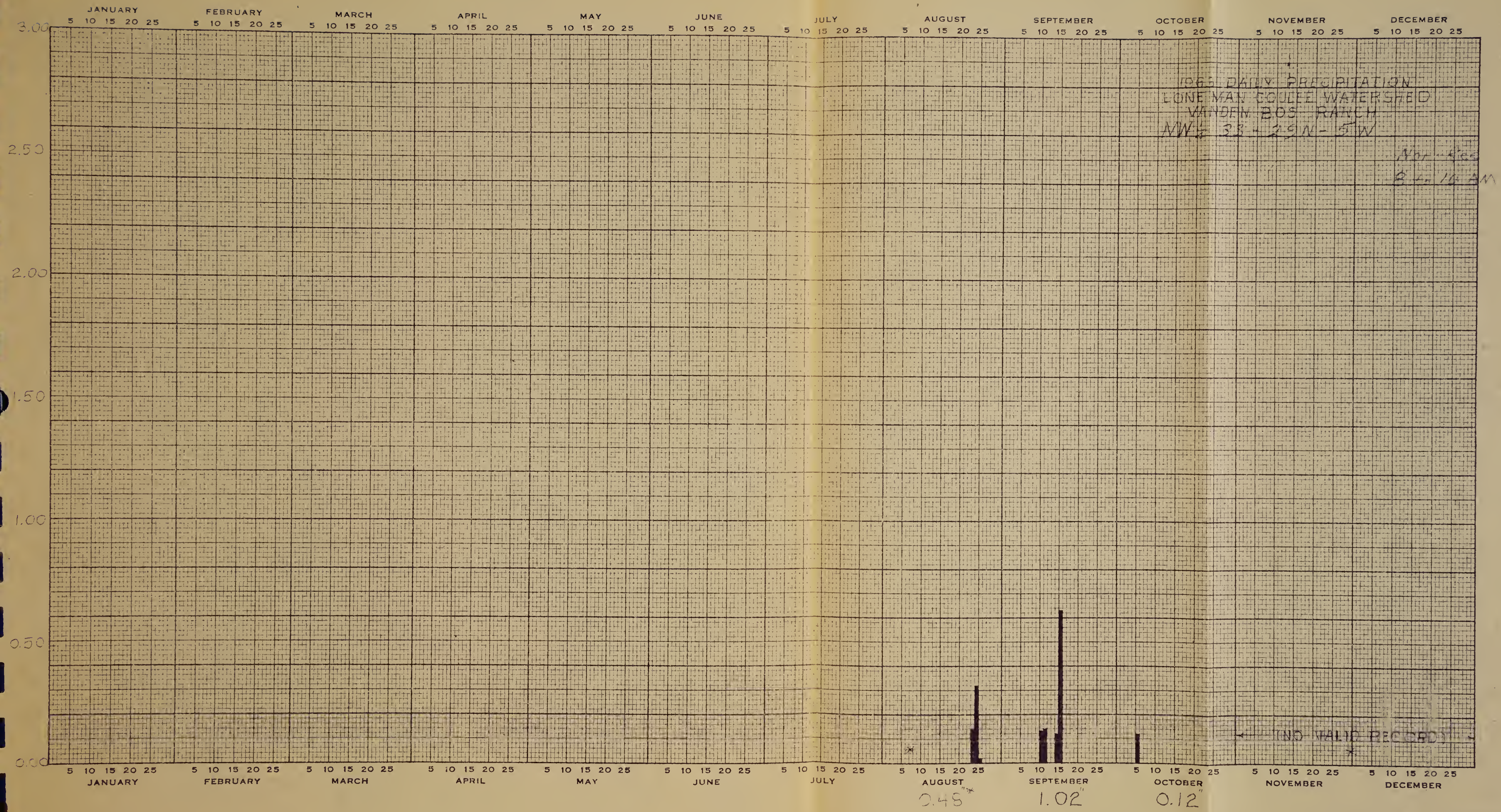


JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0.25	0.31	0.64	1.16	1.23	6.00	1.59	1.63	1.72	0.02	0.15	0.10

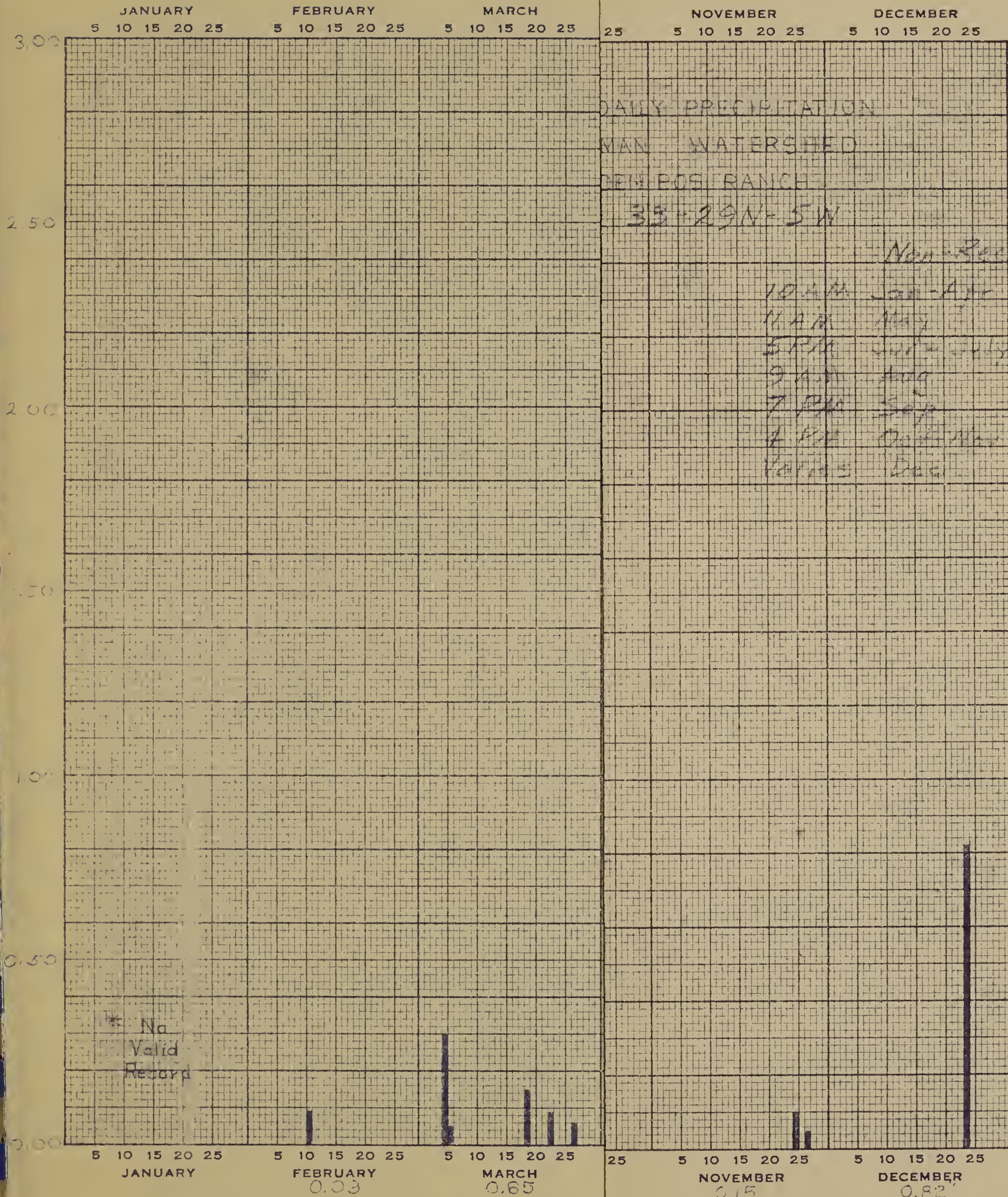
TOTAL: 14.80
1965



TOTAL: 1.62"*
AUG. — OCT. 1963

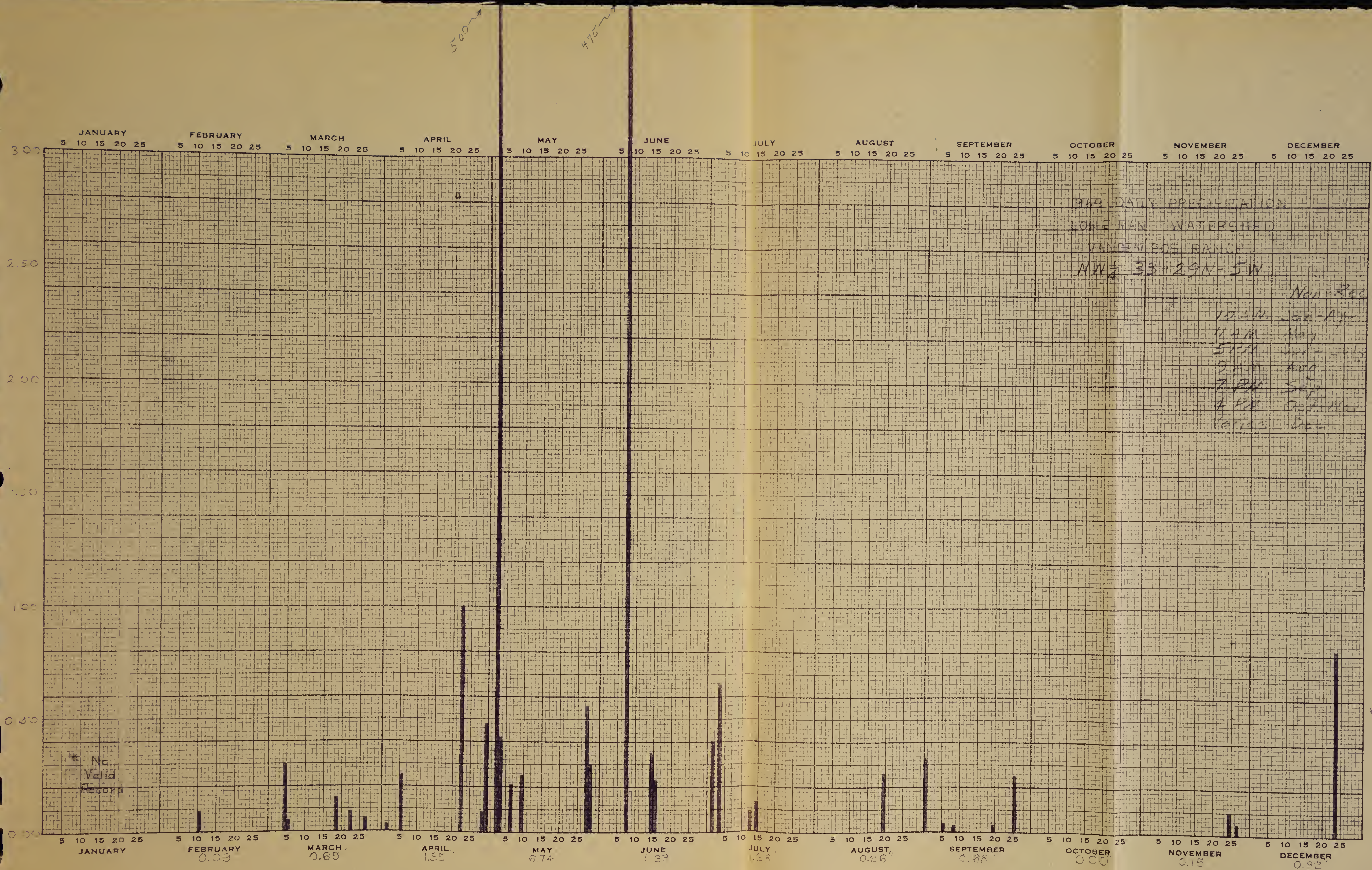


TOTAL: 1.62"*
AUG. – OCT. 1963



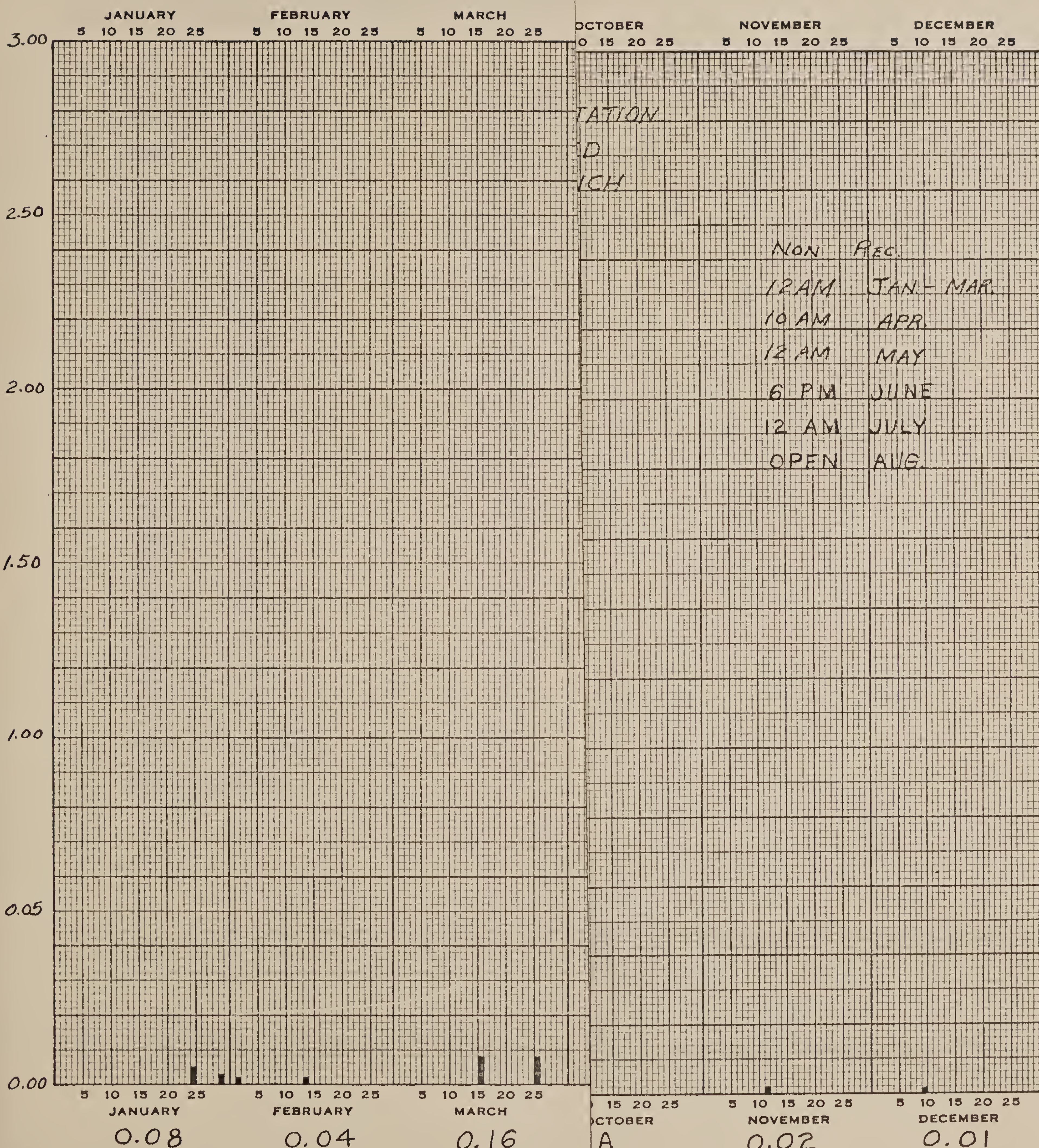
TOTAL 17.85" *

1964

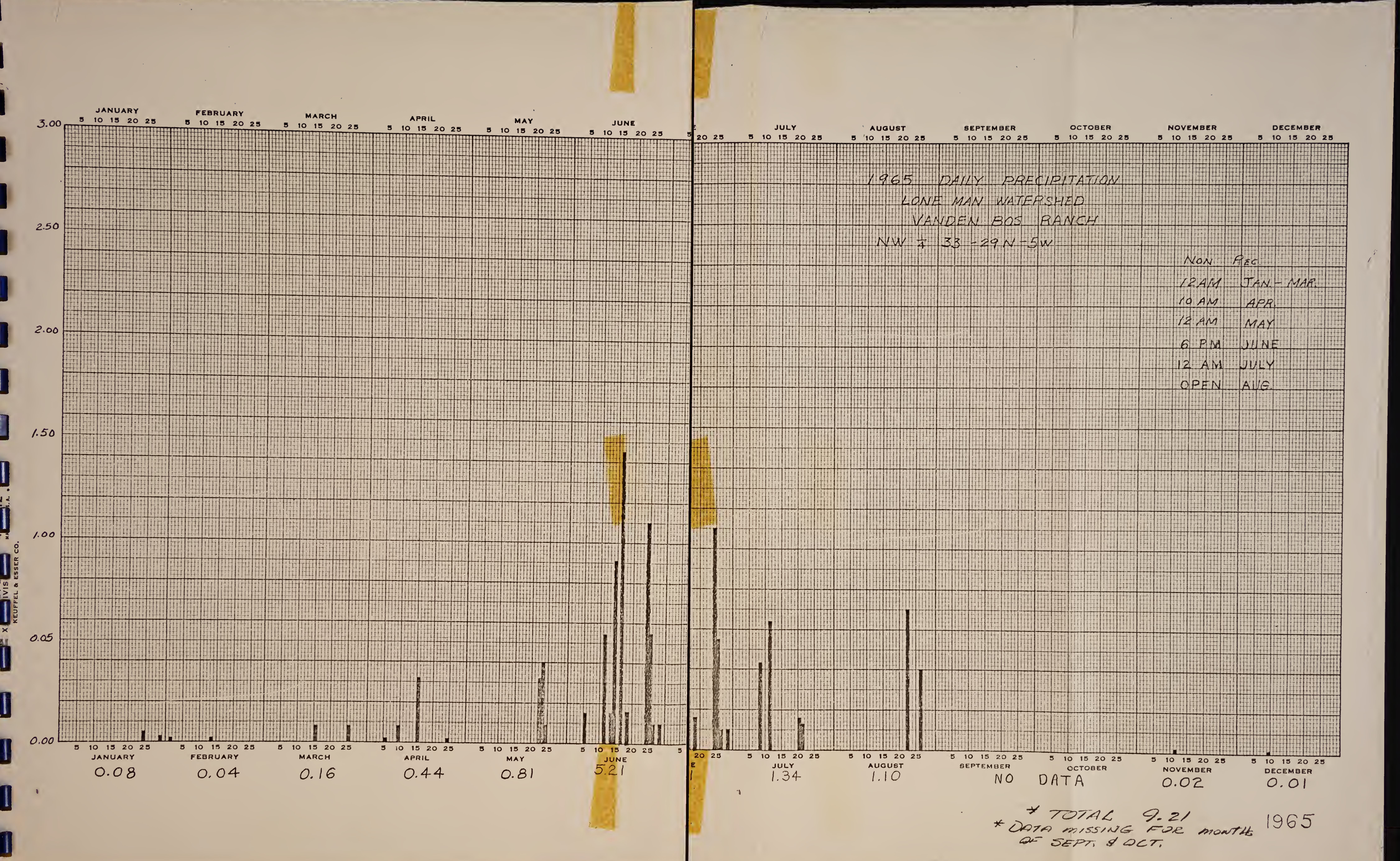


TOTAL 17.85" *

1964



OTAL 9.21 1965
nissing FOR months
PT. & OCT.



1965 DAILY PRECIPITATION
LONE MAN WATERSHED
VANDEN BOS RANCH
NW 1/4 33-29N-5W
NON REC
12AM JAN.-MAR.
10 AM APR.
12 AM MAY
6 PM JUNE
12 AM JULY
OPEN AUG.
3.00
2.50
2.00
1.50
1.00
0.05
0.00
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
0.08
0.04
0.16
0.44
0.81
5.21
1.34
1.10
NO DATA
0.02
0.01
* TOTAL 9.21
* DATA MISSING FOR MONTHS OF SEPT. & OCT.
1965

The following tabulation shows peak flows recorded at Lone Man Coulee since installation of the water stage recorder:

March 30, 1964	45 cfs	3.19 cfs/sq in
April 12, 1964	18	1.28
May 3, 1964	195	13.82
June 8, 1964	1740	123.4
June 17, 1964	26	1.84
Feb. 17, 1965	390	27.65
Feb. 27, 1965	29	2.06
Mar. 31, 1965	34	2.41
Apr. 1, 1965	68	4.82
Apr. 5, 1965	63	4.46
Apr. 6, 1965	240	17.0
Apr. 7, 1965	60	4.25
Apr. 8, 1965	17	1.20
Apr. 9, 1965	11	0.78
Apr. 11, 1965	18	1.28
Apr. 12, 1965	18	1.28
Apr. 17, 1965	32	2.27
June 17, 1965	110	7.80
June 25-26, 1965	200	14.2
July 12, 1965	44	3.12

APPENDIX C

THEORETICAL BASIS FOR CONFIDENCE CURVES

The reduced standard error (r.s.e.) for a population of extreme values (for large values of sample size, n) is given by

$$\sqrt{\alpha^2 N \sigma^2(x)} = \sqrt{\pi^2/6 + 1.1396(x-\gamma)\pi/\sqrt{6} + 1.1(x-\gamma)^2}$$

where α is the slope of the theoretical distribution with respect to the reduced variate on its probability paper. γ is the population mean, $\sigma(x)$ is the standard deviation of the population, and x, is the value of the reduced variate. For the order statistic of minimum variance this reduces to a function of only the return period (Gumbel, "Statistics of Extremes," pp. 212-216, 227-229). These results are given in Table III.

The reduced standard error is related to the standard error of the mth value of y by

$$\sigma(y_m) = (r.s.e.)/\sqrt{n}\,\alpha ,$$

(Gumbel p. 53). The value of α, according to the Gumbel plotting procedure is estimated by

$$a = \sigma_n / s_x ,$$

where s_x is the standard deviation of the reduced extremes, and σ_n is a function only of the sample size. The equation of the confidence curves is given by

$$y_{cc} = y_t \pm \sigma(\hat{y}_m)$$

where $_{cc}$ is the value of the variate on the confidence curve and y_t is the value of the variate on the Gumbel line.

Combining (1), (2) and (3) gives

$$y_{cc} = y_t \pm (r.s.e.)(s_x)/(\sigma_n\sqrt{n}) ,$$

which is the equation given in the text.

The above method can be applied as an approximation for other plotting techniques besides the Gumbel Procedure, in which case y_t becomes the ordinate of the plotted frequency line.